# IMPROVEMENT OF AN/TPQ-27 FILTER AND CONTROL TECHNIQUES

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# NAVAL POSTGRADUATE SCHOOL

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# THESIS

IMPROVEMENT OF AN/TPQ-27 FILTER
AND CONTROL TECHNIQUES

by

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# Improvement of AN/TPQ-27

# Filter and Control Techniques

by

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## ABSTRACT

A modified linear Kalman filter with deterministic forcing is used to improve the tracking capabilities of the Marine Corps AN/TPQ-27 remote tactical aircraft guidance system. Both sixth and ninth order filters are developed and used with the Precision and Coarse Guidance simulation programs. A technique for overcoming the effects of auto-pilot bias is presented and tested through simulation. Precision Guidance control is modified to utilize angle error and angle error rate to generate corrective commands. Significant improvement in aircraft state estimation, bombing accuracy, and overall system response is shown. The Coarse Guidance algorithms and simulation program are nearly completely new and perform aircraft guidance to the bombing run with more than adequate precision under simulated conditions. The new version of the program is significantly less complex than the previous version and incorporates features which more realistically reflect actual conditions under which the system would be used.

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# I. INTRODUCTION

## A. AN/TPQ-27 INTRODUCTION

The AN/TPQ-27 system is a tactical aircraft guidance and control system used by the Marine Corps to guide strike force aircraft along a preplanned route, and then down a final leg for the purpose of performing precision bombing.

The mission control and guidance is divided into two modes. The first mode, called Coarse Guidance, takes the aircraft from a TACAN entry point through a series of straight paths and command turns. These "legs" of the Coarse Guidance run are defined by the leg end points. The actual route to be followed is determined by tactical considerations. The last leg is also the bombing leg. After proper entrance onto the final approach to the bombing leg, the second mode of the mission guidance control takes command; this is called Precision Guidance. During the Precision Guidance mode, very accurate aircraft position estimates are developed to enable bomb placement calculations which will be accurate to errors on the order of feet at the final impact point. The primary difference between these two modes, other than purpose, is the radar precision used to make the measurement of aircraft position. The resultant precision is also a function of the data rates of the respective radars, which differ significantly in this case.

The initial efforts on this system have suffered from some problems which are also apparent from observation of the

results of software simulations of actual missions. The purpose of this study was to look into various techniques currently employed in the simulation programs, and attempt to improve the response and overall accuracy of the system through the use of different and/or improved algorithms.

## B. AN/TPQ-27 PROBLEM AREA DEFINITION

The specific problem areas which were investigated were defined primarily through contact with personnel closely associated with the system's performance. Other areas were noted as in need of improvement during the familiarization and simulation trial phases of study.

### 1. Problem Areas in Coarse Guidance

Coarse guidance has suffered from many separate but related problems. Pilots have complained that the controls sent to the aircraft in the final moments before turning to a new leg have been violent. In addition, there have been complaints of not knowing where the aircraft was at any time other than having just exited from a "command turn," i.e., a turn from one leg onto a new leg, vice a course correction. The simulation program was found to be suffering from unnecessary complexity in some areas, and was apparently in need of refined estimation and control procedures.

### 2. Problem Areas in Precision Guidance

The single most prevalent complaint with the Precision Guidance program was the length of time required for the estimates to stabilize in order than an accurate determination on exactly when the bomb should be dropped could be made.

Again, this and other related problems with Precision Guidance seemed due to inadequate aircraft estimation algorithms, and a control scheme which was too simplistic in design.

## II. AIRCRAFT POSITION AND VELOCITY ESTIMATION

### A. BACKGROUND AND INTRODUCTION TO THE KALMAN FILTER

The technique previously used to provide noise filtering on aircraft position and velocity was a standard alpha-beta filter with parameters chosen to yield the "optimal" tracking capability in accordance with the theory developed in [1]. However, this reference also states that in the case when adaptive tracking is required, the $\alpha$ parameter should be permitted to vary with observed high frequency power fluctuations in the error signal

$$e = x_n - x_{pn} \tag{1}$$

where $x_n$ is the state estimation, and $x_{pn}$ is the state prediction prior to measurement. Provisions for this variation were not included in the tracking algorithm which was implemented. In addition, the alpha-beta filter which was implemented was not an unbiased estimator of the aircraft state vector. This is due to the fact that as controls were used to cause changes in the free inertial model of the motion assumed by the alpha-beta filter, no corresponding changes were added to the filter states to account for this deterministically added control. This accounts for the exceptionally large and prolonged transient errors which resulted from large control bank commands.

The Kalman filter yields a minimum variance estimate of the state vector when the statistics of the noise are as

described below. This filter includes the effects of deterministic control commands to the aircraft to yield an estimator which is very nearly unbiased. The greatest improvement in estimation is yielded during the initial filter transient behavior. This is particularly critical in this application, in order to overcome the long filter settling period required by the alpha-beta filter.

## B. KALMAN FILTER ASSUMPTIONS AND GENERAL RECURSION EQUATIONS

Application of the Kalman filter assumes that the discrete system under consideration satisfies

$$X(k+1) = \phi(k)X(k) + W(k) \tag{2}$$

$$Z(k) = H(k)X(k) + V(k) \tag{3}$$

where X is an n x 1 state vector, Z is an m x 1 output vector, W is a zero-mean n x 1 vector of state excitation white noise, uncorrelated with the zero-mean additive white noise vector V, $\phi$ is the state transition matrix (n x n), and H is the m x n observation or measurement matrix. The assumed noise statistics are

$$E[V(k)\ V(j)^T] = R(k)\ \delta(k,j) \tag{4}$$

$$E\{\Gamma[W(k)\ W(j)^T]\Gamma^T\} = Q(k)\ \delta(k,j) \tag{5}$$

$$E[V(k)\ W(j)^T] = 0 \text{ for all } k,j \tag{6}$$

where

$$\delta(k,j) = \begin{cases} 0 & k \neq j \\ 1 & k = j. \end{cases} \tag{7}$$

The actual Kalman filter recursion equations are summarized

below, where $\hat{X}(k/j)$ denotes the estimate of the state $X(k)$ based upon the j measurement observations $Z(1), Z(2), \ldots, Z(j)$.

$$P(k/k-1) = \phi(k,k-1)P(k-1/k-1)\phi(k,k-1)^T + Q(k) \tag{8}$$

$$G(k) = P(k/k-1)H(k)[H(k)P(k/k-1)H(k)^T + R(k)]^{-1} \tag{9}$$

$$P(k/k) = P(k/k-1) - G(k)H(k)P(k/k-1) \tag{10}$$

$$\hat{X}(k/k) = \hat{X}(k/k-1) + G(k)[Z(k) - H(k)\hat{X}(k/k-1)] \tag{11}$$

$$\hat{X}(k/k-1) = \phi(k,k-1)\hat{X}(k-1/k-1) + \Gamma(k)U(k-1) \tag{12}$$

where $P(k/k-1)$ is the covariance of error for the state prediction vector $\hat{X}(k/k-1)$, $P(k/k)$ is the covariance of error matrix for the state estimation vector $\hat{X}(k/k)$, and $G(k)$ is the gain matrix to be applied at the time of the $k^{th}$ measurement. Further detail on the summary and development of the Kalman filter equations is available in [2], [3], and [4].

C. SELECTION OF REQUIRED SYSTEM MODEL ORDER

The order of the filter refers to its capability to track a target exhibiting a particular type of motion without error, in a noiseless environment. For a single dimensional problem, a first order filter would estimate position only. Second order filters are capable of tracking a constant velocity target and estimating both position and velocity. Similarly, third order filters are capable of tracking a target exhibiting a constant acceleration profile, estimating position, velocity and acceleration in the process.

Documentation provided on the original AN/TPQ-27 programs indicated that the aircraft would be flying a constant airspeed

profile. This then indicates that the aircraft model might be appropriately chosen to be a free inertial ($1/s^2$) plant. Command orders to the aircraft in the form of bank angles serve to change the aircraft's heading in a totally deterministic manner, provided the true transfer function of the aircraft is known with respect to roll response. In view of the above, it was originally thought that it would be sufficient to implement second order Kalman filters to estimate position and velocity in each of the three coordinates, yielding a sixth order filter.

It was later discovered that a problem known as autopilot bank angles bias exists with sufficient frequency and resultant imprecision that the order of the original feedback loop was increased to compensate for the error through the use of a discrete integrator [5]. Concepts such as integrators and digitally implemented lead-lag networks were to be avoided in the improved version of the simulation routines due to the resultant phase lags which they introduce. This is not to say that the steady-state response is in error, but simply that the time to reach that state is unsatisfactorily long. When simulations were run with non-zero autopilot bias bank angles in conjunction with second order Kalman filters, significant errors resulted.

A bias angle causes the aircraft to turn in a given direction at a constant heading rate. It was postulated that it might be possible to estimate the bias angle, and induce an anti-bias in the estimator, but the noise on the bias estimate proved to be excessive.

Third order filters will estimate a constant acceleration. The second attempt to overcome the bias problem was to postulate that the acceleration in the horizontal components would not change significantly over the relatively short periods of flight time in question. (Of course, if a bias existed and the aircraft was flown for a long enough time, the path flown would appear as a circle, and the third order filters could not possibly be satisfactory for that situation.) Thus, development of two separate filtering schemes was pursued. A sixth order (second order for each of three dimensions of motion) and a ninth order (third order for each of the three dimensions) filter were developed and tested. Use of the programs is very similar for each of the filters and is described below.

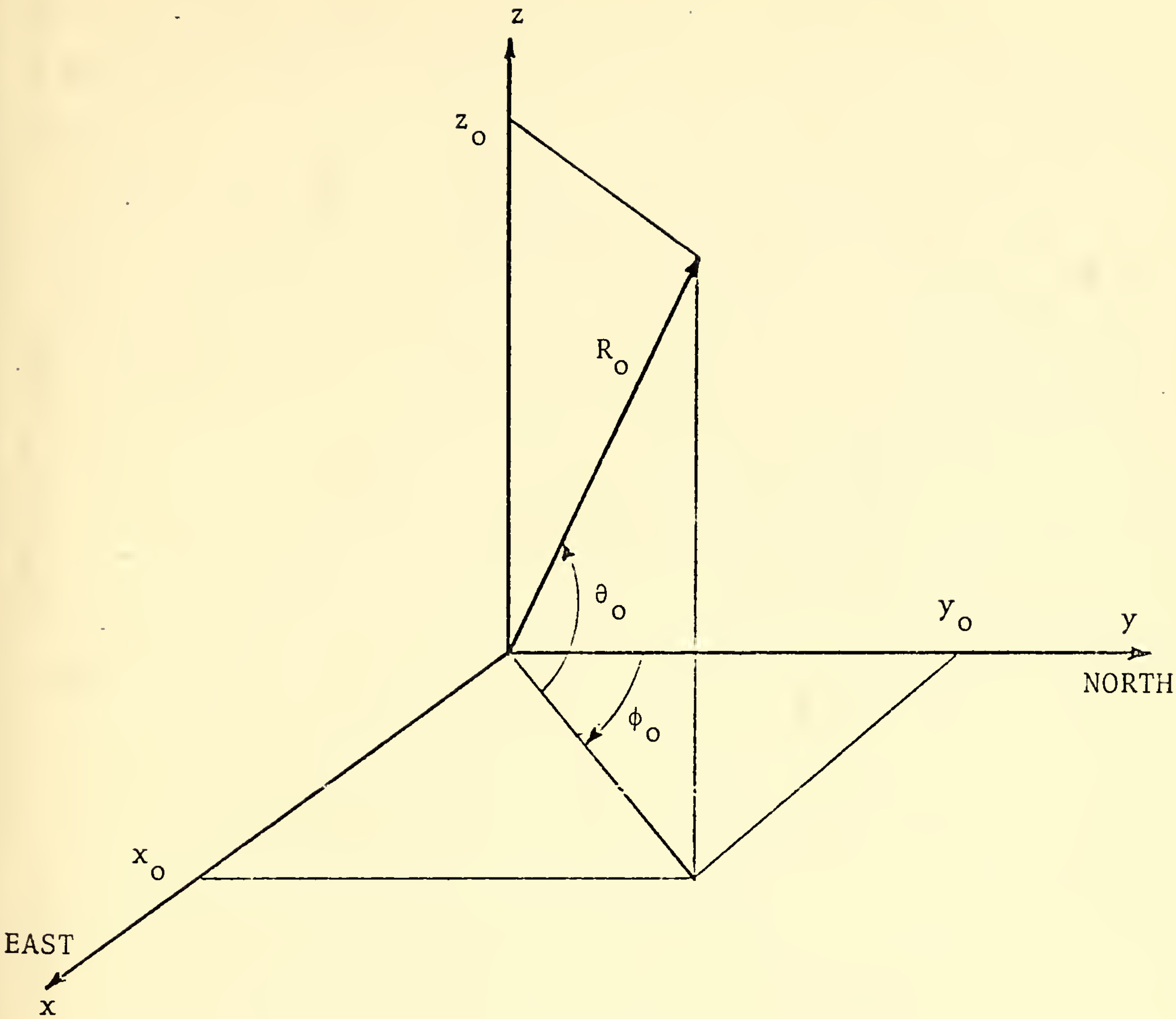
## D. DERIVATION OF THE COVARIANCE OF MEASUREMENT NOISE MATRIX, R(k)

The Kalman Filter assumptions include linear relationships among measurements and states, as well as linear state transition dynamics. The first of these is of concern at this point. The states of concern in measurement have been selected as Cartesian coordinates (x,y,z). However, the radar measures range, azimuth, and elevation. The assumed relationship between the states and the measured values are as shown in Fig. 1 and given by the equations below.

$$x = R \cos\theta \sin\phi \qquad (13)$$

$$y = R \cos\theta \cos\phi \qquad (14)$$

$$z = R \sin\theta \qquad (15)$$




$$x_o = R_o \cos\theta_o \sin\phi_o$$

$$y_o = R_o \cos\theta_o \cos\phi_o$$

$$z_o = R_o \sin\theta_o$$

Figure 1. Illustration of assumed coordinate system used in the radar filters.

where R is the range to the aircraft, $\theta$ is the elevation angle, and $\phi$ is the azimuth angle of the aircraft from North.

Note that this form departs from that as given in (3) since the relationship between the measured variables and the states is a nonlinear one. If the states were directly observable, then (3) would appear as

$$\begin{bmatrix} z1(k) \\ z2(k) \\ z3(k) \end{bmatrix} = H(k)\ X(k) + \begin{bmatrix} v1(k) \\ v2(k) \\ v3(k) \end{bmatrix} \tag{16}$$

where for a sixth order system

$$H(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \tag{17}$$

and

$$X(k) = [x(k)\ \dot{x}(k)\ y(k)\ \dot{y}(k)\ z(k)\ \dot{z}(k)]^T. \tag{18}$$

Similarly, for a ninth order system

$$X(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{19}$$

and (20)

$$X(k) = [x(k)\ \dot{x}(k)\ \ddot{x}(k)\ y(k)\ \dot{y}(k)\ \ddot{y}(k)\ z(k)\ \dot{z}(k)\ \ddot{z}(k)]^T.$$

Thus, in both cases the equations reduce to

$$\begin{bmatrix} z1(k) \\ z2(k) \\ z3(k) \end{bmatrix} = \begin{bmatrix} x(k) \\ y(k) \\ z(k) \end{bmatrix} + \begin{bmatrix} v1(k) \\ v2(k) \\ v3(k) \end{bmatrix} \tag{21}$$

where $v1(k)$ is the $k^{th}$ component of noise added to the x coordinate, $v2(k)$ is the $k^{th}$ component of noise added to the y coordinate, and $v3(k)$ is the $k^{th}$ component of noise added to the z coordinate. Due to the linearity of this problem, the three coordinate components might be considered as being statistically independent, in which case the $R(k)$ matrix would probably be a diagonal array consisting of the individual coordinate measurement variances which would be constant for all k. For the nonlinear radar problem, the relationships for each k are

$$z1 = (R + n_r) \cos(\theta + n_\theta) \sin(\phi + n_\phi) \tag{22}$$
$$= x + v1$$

$$z2 = (R + n_r) \cos(\theta + n_\theta) \cos(\phi + n_\phi) \tag{23}$$
$$= y + v2$$

$$z3 = (R + n_r) \sin(\theta + n_\theta) \tag{24}$$
$$= z + v3$$

where $n_r$, $n_\theta$, and $n_\phi$ are incremental noise disturbances to the true range, elevation and azimuth, respectively. Expanding (22) yields

$$z1 = (R + n_r)[\cos\theta \cos n_\theta - \sin\theta \sin n_\theta] \cdot [\sin\phi \cos n_\phi + \cos\phi \sin n_\phi]. \tag{25}$$

It is assumed that $n_\theta$ and $n_\phi$ are small angle perturbations, and therefore that

$$\cos n_\theta \doteq \cos n_\phi \doteq 1 \tag{26}$$

$$\sin n_\theta \doteq n_\theta \tag{27a}$$

$$\sin n_\phi \doteq n_\phi \qquad (27b)$$

(25) can then be written as

$$z1 \doteq (R + n_r)[\cos\theta \sin\phi - n_\theta \sin\theta \sin\phi \qquad (28)$$

$$+ n_\phi \cos\theta \cos\phi - n_\theta n_\phi \sin\theta \cos\phi]$$

$$\doteq R \cos\theta \sin\phi + v1 \qquad (29)$$

where

$$v1 \doteq -Rn_\theta \sin\theta \sin\phi + Rn_\phi \cos\theta \cos\phi - Rn_\theta n_\phi \sin\theta \cos\phi$$

$$+ n_r \cos\theta \sin\phi - n_r n_\theta \sin\theta \sin\phi + n_r n_\phi \cos\theta \cos\phi$$

$$- n_r n_\theta n_\phi \sin\theta \cos\phi. \qquad (30)$$

Similar developments for the z1 and z2 measurements yields

$$v2 \doteq -Rn_\theta \sin\theta \cos\phi - Rn_\phi \cos\theta \sin\phi + Rn_\theta n_\phi \sin\theta \sin\phi$$

$$+ n_r \cos\theta \cos\phi - n_r n_\theta \sin\theta \cos\phi - n_r n_\phi \cos\theta \sin\phi$$

$$+ n_r n_\theta n_\phi \sin\theta \sin\phi \qquad (31)$$

and

$$v3 \doteq Rn_\theta \cos\theta + n_r \sin\theta + n_r n_\theta \sin\theta. \qquad (32)$$

Repeating (4), the equation for the covariance of measurement error matrix is

$$R(k) = E\left\{\begin{bmatrix} v1(k) \\ v2(k) \\ v3(k) \end{bmatrix} [v1(k)\ v2(k)\ v3(k)]\right\}. \qquad (33)$$

It is assumed that $n_r$ is much smaller than R. Evaluating the diagonal terms of R(k) yields

$$R(1,1) \doteq R^2\sigma_\theta^2 \sin^2\theta \sin^2\phi + R^2\sigma_\phi^2 \cos^2\theta \cos^2\phi$$
$$+ R^2\sigma_\theta^2\sigma_\phi^2 \sin^2\theta \cos^2\phi + \sigma_r^2 \cos^2\theta \sin^2\phi \qquad (34)$$

$$R(2;2) \doteq R^2\sigma_\theta^2 \sin^2\theta \cos^2\phi + R^2\sigma_\phi^2 \cos^2\theta \sin^2\phi$$
$$+ R\sigma_\theta^2\sigma_\phi^2 \sin^2\theta \sin^2\phi + \sigma_r^2 \cos^2\theta \cos^2\phi \tag{35}$$

$$R(3,3) \doteq R^2\sigma_\theta^2 \cos^2\theta + \sigma_r^2 \sin^2\theta. \tag{36}$$

The off-diagonal elements are simply the expected values of the cross product terms, and are computed in the same way yielding

$$R(1,2) \doteq R^2\sigma_\theta^2(1 - \sigma_\theta^2)(\sin^2\theta \sin\phi \cos\phi)$$
$$+ (\sigma_r^2 - R^2\sigma_\phi^2)(\cos^2\theta \sin\phi \cos\phi) \tag{37}$$

$$R(2,3) \doteq (\sigma_r^2 - R^2\sigma_\theta^2)(\sin\theta \cos\theta \cos\phi) \tag{38}$$

$$R(1,3) \doteq (\sigma_r^2 - R^2\sigma_\theta^2)(\sin\theta \cos\theta \sin\phi). \tag{39}$$

Due to the symmetry of the R(k) array, it is also true that

$$R(2,1) = R(1,2) \tag{40}$$

$$R(3,1) = R(1,3) \text{ and} \tag{41}$$

$$R(3,2) = R(2,3). \tag{42}$$

Note that the R(k) matrix is in fact not a constant array, but is one which is state dependent, or rather R, $\theta$, and $\phi$ dependent.

## E. STATE PREDICTION EQUATIONS

The state prediction equations are used to predict ahead from the current estimate to some arbitrary future point in time. Normally this time is that of the next measurement, however, this is not always the case. As a relevant example, in Coarse Guidance, it is required to predict ahead several times between radar samples, due to the long sampling interval

of the radar, and the need to precisely determine times to order command turns.

1. <u>State Prediction in the Linear Case</u>

The analysis which follows will be addressed primarily to the ninth order case. The state vector is given in (20). The strictly linear prediction equations are given by (12) where

$$\phi(k,k-1) = \left[\begin{array}{ccc|ccc|ccc} 1 & T & \frac{T^2}{2} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & T & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 1 & T & \frac{T^2}{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & T & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 & 1 & T & \frac{T^2}{2} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & T \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right] \qquad (43)$$

$$\Gamma(k) = \begin{bmatrix} T^3/6 & 0 & 0 \\ T^2/2 & 0 & 0 \\ T & 0 & 0 \\ 0 & T^3/6 & 0 \\ 0 & T^2/2 & 0 \\ 0 & T & 0 \\ 0 & 0 & T^3/6 \\ 0 & 0 & T^2/2 \\ 0 & 0 & T \end{bmatrix} \qquad (44)$$

and

$$U(k) = [\dot{a}_x(k) \quad \dot{a}_y(k) \quad \dot{a}_z(k)]^T. \tag{45}$$

Note that although in general the $\phi$ and $\Gamma$ matrices are functions of k, in this case they are not. This is an arbitrary choice. Normally, T represents the interval between sampling points and is a constant. If one wished to predict ahead by 2T, he could either perform the prediction operation twice in succession, or simply compute a new $\phi$ and $\Gamma$ matrix using 2T in place of T. The former technique is used in this study.

The U(k) array represents the deterministic forcing for each of the three dimensions; the units are distance per $sec^3$ since the forcing is an acceleration rate. (For the sixth order filter U(k) is an acceleration (distance/$sec^2$).) This must be a function of k since at each time point the control to the aircraft may be different, and in general will be different.

The above linear prediction equations of motion are those which would normally be used in a Kalman Filter. However, it was found that these equations did not yield results of sufficient accuracy. A nonlinear technique was required to obtain precise results. This is derived below, along with the equations for aircraft response to a bank angle command.

2. Aircraft Response to Bank Commands

The aircraft is sent bank angle commands in order to cause heading changes. The flight profile is assumed to be a coordinated turn, in which there is no motion in the vertical plane, and the heading rate change is proportional to the

bank angle, as described in [6]. The relationship is

$$\dot{\psi} = (g/V)\ \phi_a \tag{46}$$

where $\dot{\psi}$ is the heading rate in degrees/sec, g is the earth's gravitational constant (32.2 ft/sec$^2$), V is the airspeed in ft/sec, and $\phi_a$ is the actual angle of bank.

The roll transfer function of the aircraft can be approximated by

$$\frac{\phi(s)}{\phi_c(s)} = 1/(s\tau_b + 1) \tag{47}$$

as given in [6], where $\tau_b$ is the response time constant. $\tau_b$ is a function of the particular aircraft in use. The discretized version of the solution to the differential equation resulting from (47) is

$$\phi(k) = \phi_c(k-1)(1 - e^{-T/\tau_b}) + \phi(k-1)e^{-T/\tau_b} \tag{48}$$

where T is the interval between predictions, $\phi_c$ is the commanded bank angle, and $\phi(k)$ is the actual bank angle at time T(k). Then the turning rate is

$$\dot{\psi}(k) = (g/V)\ \phi(k). \tag{49}$$

To get the incremental heading angle change over the time T, integrate (49).

$$\Delta\psi(k) = \int_o^T \dot{\psi}\ dt = (g/V) \int_o^T \phi(k)\ dt \tag{50}$$

$$= (g/V) \left[ \phi_c(k)t + (\phi(k-1) - \phi_c(k)) \frac{e^{\frac{-t}{\tau_b}}}{\frac{-1}{\tau_b}} \right] \Bigg|_o^T$$

$$= (g/V)[\phi_c(k)T + (\phi(k-1) - \phi_c(k))(\tau_b)(1 - e^{-T/\tau_b})]. \tag{50}$$

Then

$$\psi(k) = \psi(k-1) + \Delta\psi(k). \tag{51}$$

3. State Prediction in the Nonlinear Case

A ninth order filter is assumed for this analysis. The analysis includes effects of wind motion in x and y, and assumes knowledge of the wind components. Since the filter assumes a constant acceleration track, the acceleration prediction equations are

$$\ddot{x}(k/k-1) = \ddot{x}(k-1/k-1) \tag{52a}$$

$$\ddot{y}(k/k-1) = \ddot{y}(k-1/k-1) \tag{52b}$$

$$\ddot{z}(k/k-1) = \ddot{z}(k-1/k-1). \tag{52c}$$

Since the new heading is known in terms of the command bank angle, the predicted velocities are

$$\hat{\dot{x}}(k/k-1) = \hat{V}(k-1)\sin[\psi(k)] + W_x + \hat{\ddot{x}}(k-1/k-1)T \tag{53a}$$

$$\hat{\dot{y}}(k/k-1) = \hat{V}(k-1)\cos[\psi(k)] + W_y + \hat{\ddot{y}}(k-1/k-1)T \tag{53b}$$

$$\hat{\dot{z}}(k/k-1) = \hat{\ddot{z}}(k-1/k-1)T \tag{53c}$$

where $\hat{V}(k-1)$ is the estimated air speed at time $T(k-1)$, and $W_x$ and $W_y$ are the estimated wind components. The predicted position is approximated through the use of numerical integration using the Euler-Maclaurin summation formula, retaining only the first correction term. In general, this formula is given by [7] as

$$\int_{t_o}^{t_n} f(t)dt \simeq T \sum_{i=0}^{n} f_i - \frac{T}{2}(f_o + f_n) - \frac{T^2}{12}(f'_n - f'_o) + \cdots \text{h.o.t.} \tag{54}$$

The equations involving the integrals are

$$\hat{x}(k/k-1) = \hat{x}(k-1/k-1) + \int_{T(k-1)}^{T(k)} \dot{x}(t)\, dt \tag{55a}$$

$$\hat{y}(k/k-1) = \hat{y}(k-1/k-1) + \int_{T(k-1)}^{T(k)} \dot{y}(t)\, dt \tag{55b}$$

$$\hat{z}(k/k-1) = \hat{z}(k-1/k-1) + \int_{T(k-1)}^{T(k)} \dot{z}(t)\, dt\ . \tag{55c}$$

Applying (54) yields

$$\begin{aligned}\hat{x}(k/k-1) \doteq\ & \hat{x}(k-1/k-1) + \frac{T}{2}\,[\hat{\dot{x}}(k-1/k-1) + \hat{\dot{x}}(k/k-1)] \\ & - \frac{T^2}{12}\,[\hat{\ddot{x}}_t(k/k-1) - \hat{\ddot{x}}_t(k-1/k-1)]\end{aligned} \tag{56a}$$

$$\begin{aligned}\hat{y}(k/k-1) \doteq\ & \hat{y}(k-1/k-1) + \frac{T}{2}\,[\hat{\dot{y}}(k-1/k-1) + \hat{\dot{y}}(k/k-1)] \\ & - \frac{T^2}{12}\,[\hat{\ddot{y}}_t(k/k-1) - \hat{\ddot{y}}_t(k-1/k-1)]\end{aligned} \tag{56b}$$

$$\hat{z}(k/k-1) \doteq T\ \hat{\dot{z}}(k/k-1) \tag{56c}$$

where $\ddot{x}_t$ and $\ddot{y}_t$ represent total accelerations in x and y. The simplification of the equation used to predict altitude is a result of the fact that there is no deterministic forcing in that direction.

A discussion of the relationship between the acceleration estimate $\hat{\ddot{X}}(k/k-1)$ and the total accelerations shown in (56a) and (56b) is required at this point. The purpose of estimating an acceleration is due to the fact that bias bank angles exist which tend to cause a continuous turning motion,

and thus additional and unknown accelerations in the x and y directions. The prediction method as described above will place the aircraft at exactly the correct point with the correct velocity if there is no bias. In this case, the estimator will estimate that zero additional acceleration is present. In the case in which an unknown bias bank angle is present, the prediction equations will not be moving the aircraft heading angle the correct number of degrees/sec and thus lag will develop in the filter. This lag will cause a non-zero acceleration to be estimated, and this value will subsequently be added appropriately to the respective velocity components in order to compensate for the insufficient motion.

In summary, the acceleration estimate is not an estimate of the total acceleration, but is only an estimate of that acceleration which is unknown, due possibly to a variety of causes, but due primarily to an unknown bias angle in the autopilot roll reference. Thus the derivatives with respect to time of the velocity components in (56a) and (56b) do not equate to the acceleration estimates. Rather, they may be computed by differentiating equations (53) with respect to time and assuming that $\hat{\ddot{X}}(k-1/k-1)$ is approximately constant. This yields

$$\hat{\ddot{x}}_t(k/k-1) = \hat{V}(k-1) \cos[\psi(k)]\dot{\psi}(k) \tag{57a}$$

$$\hat{\ddot{y}}_t(k/k-1) = -\hat{V}(k-1) \sin[\psi(k)]\dot{\psi}(k) \tag{57b}$$

and

$$\hat{\ddot{x}}_t(k-1/k-1) = \hat{V}(k-1)\cos[\psi(k-1)]\,\dot{\psi}(k-1) \tag{58a}$$

$$\hat{\ddot{y}}_t(k-1/k-1) = -\hat{V}(k-1)\sin[\psi(k-1)]\,\dot{\psi}(k-1). \tag{58b}$$

## F. KALMAN FILTER IMPLEMENTATION

Two separate Kalman filter subroutines were developed to simulate the operation and filtering of the radar processor. RADAR6 is the sixth order filter and RADAR9 is the ninth order filter. Their implementation in software is very similar; the differences are described below along with specific characteristics of the Kalman filter which apply to both versions. A general flow diagram for the filter is presented as Fig. 2.

### 1. Differences in RADAR6 and RADAR9

The obvious difference between the two filters is that one is capable of tracking a maneuvering aircraft with nonzero autopilot bank angle bias, and the other is not. This is due to the fact that the sixth order filter does not include the acceleration states in x, y, and z. The price paid for this additional estimation capability is an increase in computation time and program size. As implemented, the ninth order filter requires about 32 percent more storage allocation in memory than does RADAR6; RADAR6 requires about 76 K bytes of storage on an IBM 360-67. The increased computational time is difficult to judge since all timing data refers to the running of the overall program. The estimate for increased run time for the ninth order filter is on the order of 20 to 50 percent, depending on overall program run time.

The increased run time and storage requirements result from the requirement that the ninth order filter must have

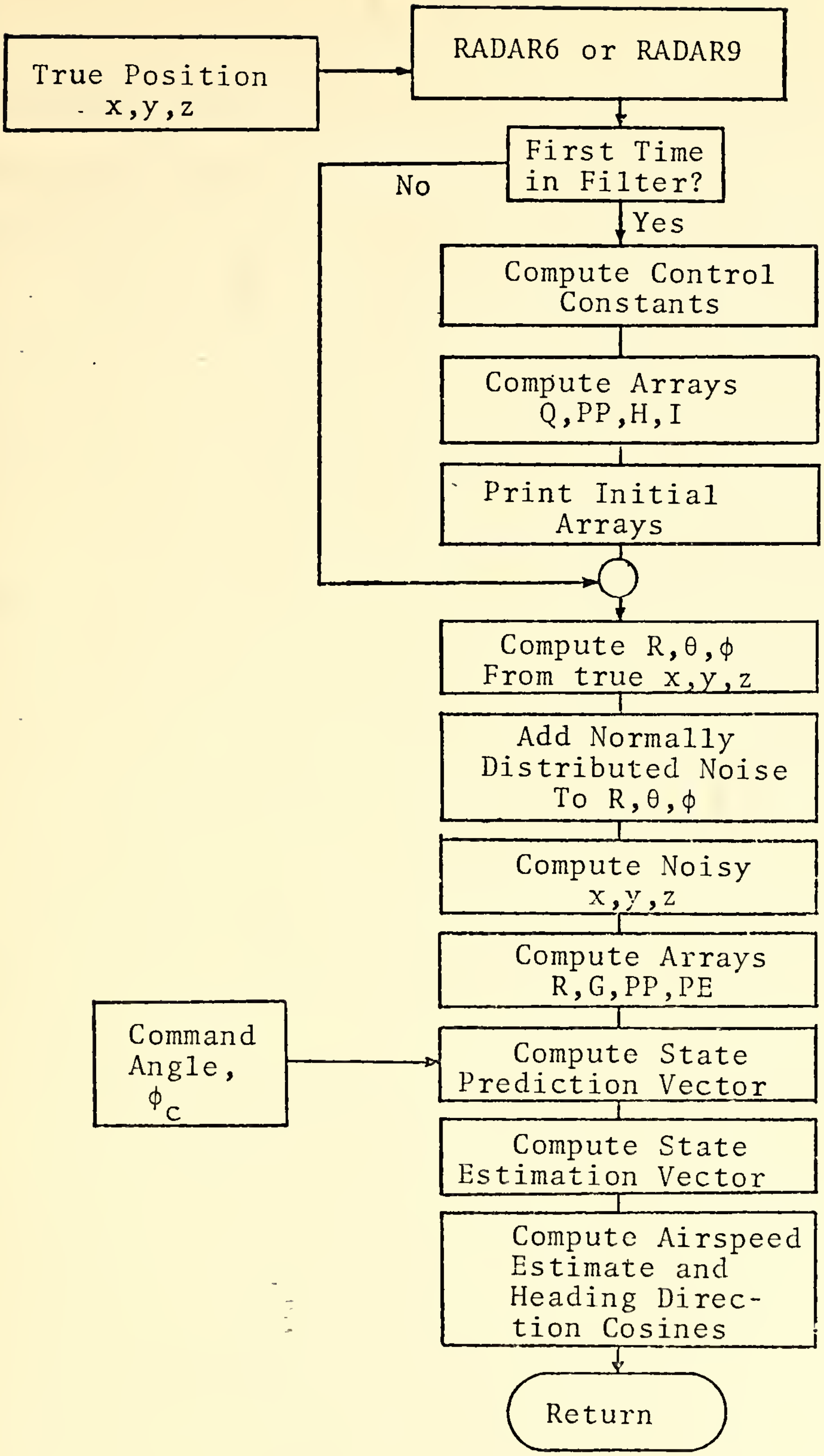



Figure 2. General block diagram of Radar Subroutines.

arrays which are 9 x 9, while the sixth order filter requires only arrays which are 6 x 6; 18 of these arrays are involved resulting in a factor of 2.25 increase in array storage alone.

The prediction calculations for the sixth order filter differ from the ninth order filter only in the fact that the acceleration terms are missing in augmenting the predicted velocity components.

RADAR6 was used to develop the Coarse Guidance program since no mention of autopilot bias problems was found in the available documentation on that original system, [8] and [9]. RADAR9 was developed directly in response to the bias problem and was therefore used exclusively in the improvement of the Precision Guidance simulation program. The two subroutines could be interchanged to work with the other simulation mode's program in a matter of minutes, should this be desired.

2. Initialization and Constant Array Calculations

Upon entering either RADAR subroutine for the first time, logic passes control through a section of constant array calculation and definition of program constants. The constants specified at this point are primarily those which are used in bank and turn angle equations. These are a function of the aircraft type and update intervals and remain constant throughout a given simulation run.

A total of five arrays are defined at the program start and remain constant. An Identity array of order equal to the filter order is set up. The Measurement matrix, (H),

as given in either (17) or (19), depending on filter order is then defined. The state transition array, $\phi$, is considered constant for this application and is defined in accordance with the filter order. The Q matrix, which is a measure of the expected unknown random forcing to be applied to the system is computed using the $\Gamma$ array as given in (44) (for the ninth order filter) in conjunction with the expected value of the random forcing array, W. For this study, W has been set to $\underline{0}$. The use and effects of non-zero values in this array are discussed below.

The covariance of the initial state prediction vector is set to $10^6$, a somewhat arbitrarily large number. The effect of choosing such a large variance on the states is to cause the filter to set the initial state estimation vector equal to the observation. In other words, the filter essentially ignores the *a priori* information set in as initial conditions. This is a very typical method of initializing a linear Kalman filter, when little confidence is placed on any initial estimate of the states. The original simulation programs followed this practice (of zero initialization) and it was continued in the improved version. However, considerable improvement in initial filter settling for the Kalman filters implemented could be achieved through the use of good initial conditions. The improved version of Coarse Guidance yields good estimates of the aircraft position, and in a "pass-off" to the Precision Guidance mode in a "live run" the states active in Coarse Guidance at the time would make

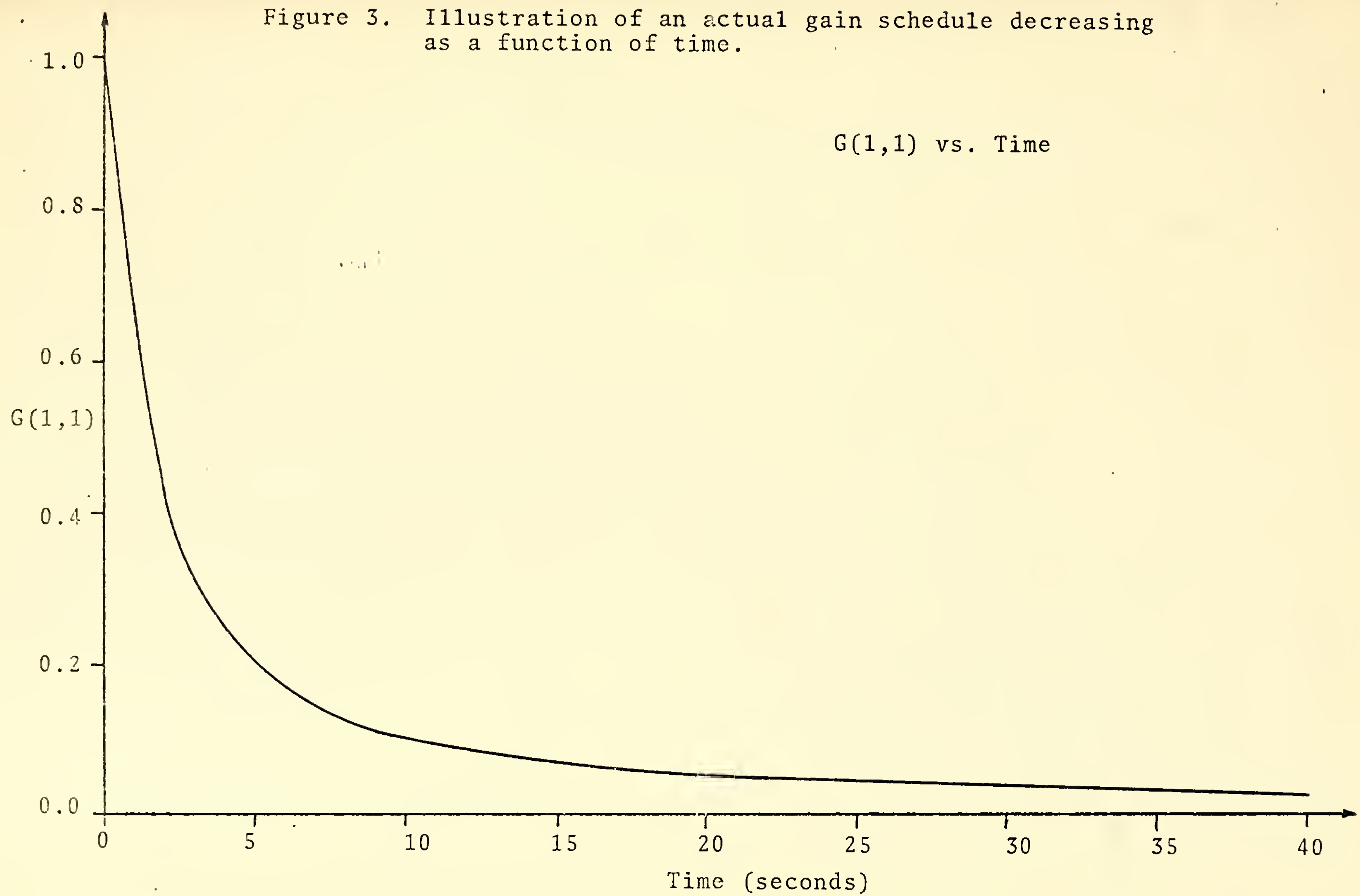
valid initial conditions for the Precision Guidance radar filter.

## G. PREDICTION ERROR, THE GAIN SCHEDULE, AND COVARIANCE OF AIRCRAFT MANEUVER

The gain matrix, G(k), determines to what extent the data will be permitted to affect the state estimation. During the initial few estimations, the data usually always plays a large role in determining states, due to the large uncertainties in the actual states specified by the large covariances of prediction and estimation. As more data is taken, the covariances fall, and there is less requirement to accept noisy data into the filter to update the state estimate. Figure 3 shows a plot of the typical gain schedule for the x coordinate, G(1,1) term as a function of time. Values for the primary gain terms in y and z are similar. The curve is approximately exponential in shape, starts essentially at 1.0 at time zero, and decreases monotonically. As can be seen from (9), the exact values in the gain matrix depend on a multitude of variables, including the states themselves in the form of the R matrix.

Absolute compliance with the Kalman filter assumptions results in a gain schedule which is optimal in the sense that the state estimates will be of minimum variance. The use of changing gains with time is implicit. Note that in the original simulation programs, only constant gain filters were used, or in a few instances, filters which started at one constant gain value and then switched to one different set of gains.

Figure 3. Illustration of an actual gain schedule decreasing as a function of time.



The gains are related to the filter bandwidth. High gains correspond to wide bandwidth since they "let in" nearly all of the measured data, including the noise on the data. Lower gains correspond to narrow band filters since very little data gets into the state estimation calculations. Use of low gains also resembles a narrow band low pass filter in the phase lag which results in the state estimation vector due to an abrupt change in the actual states. When this results, large differences begin to develop in the prediction residual of the estimation equation (11):

$$E(k) = Z(k) - H(k)\hat{X}(k/k-1). \tag{59}$$

In this case, (59) simplifies to

$$E_x = x_{data} - \hat{x}(k/k-1) \tag{60a}$$

$$E_y = y_{data} - \hat{y}(k/k-1) \tag{60b}$$

$$E_z = z_{data} - \hat{z}(k/k-1). \tag{60c}$$

As the differences in equations (60) begin to be biased either positively or negatively over a period of time, the filter will begin to integrate to a new trajectory in state space to compensate for the fact. The lower the gains, the longer this process will take.

If no random excitation noise, or no unknown forces or uncertainties are present in the system whose states are to be estimated, then the proper setting for W, the covariance of random state excitation, is $\underline{0}$. Since the Q array in (9) is

$$Q(k) = \Gamma\, E[W\, W^T]\Gamma^T, \tag{61}$$

if W is $\underline{0}$, then Q will also be $\underline{0}$. Examination of (9) in this case will reveal that as $t \to \infty$ the gain schedule will go to zero, and as a result data will have little effect on the state estimation process after a relatively short period of time after initialization. This is fine if all factors are known.

In real systems, all factors affecting the states are rarely known. Uncertainties in AN/TPQ-27 might include wind velocity, exact aircraft roll response, biases in measurement equipment, and time variations of all of these.

The goal in establishing improved simulation programs was to devise techniques which would perform the required estimation and tracking assuming the above uncertainties did not exist to a significant extent. This attitude seemed to follow that used in the generation of the original program. It was recognized that use of a gain schedule which goes to zero is not a likely useable solution to the problem; however, it did seem reasonable to try to generate a solution which worked with zero Q when the uncertainties did not exist. With this accomplished, actual utilization of the algorithms against real data will determine the extent to which the bandwidth must be opened to achieve the best results.

Selection of Q is a problem which perpetually plagues users of the Kalman filter. Any given data set will have a given Q which will yield best results in terms of a specified performance criteria, normally tracking precision. The Q cannot be selected with the benefit of hindsight, and must be chosen to yield the optimum performance over the ensemble of state trajectories of interest. The normal method for finding

this value would be to take as many raw data tracks as possible, and try to determine the Q using statistical methods.

An alternate technique to generate Q on-line through the use of prediction error is described in [10]. In this paper, Aldrick and Krabill propose the calculation of Q by the following method:

$$Q(k) = a[\mathrm{Del}(k)\ \mathrm{Del}(k)^T] + b[\mathrm{Del}(k-1)\ \mathrm{Del}(k-1)^T] \qquad (62)$$

where a and b are constants to be determined by analysis of actual data, and

$$\mathrm{Del}(k) = \hat{X}(k/k) - \hat{X}(k/k-1) \ . \qquad (63)$$

This method was investigated to a limited extent, and showed some promise if refined. Simple use of (62) seems to open the bandwidth wider than is desired. It has the advantage over the use of some constant Q for all runs that, in theory, if no uncertainties exist, the Del(k) arrays will be zero and thus Q will be $\underline{0}$. Thus, wide bandwidth is achieved only when required, as determined by prediction success. In practice however, it was found that this method caused the gains to oscillate, and created excessive error.

## H. REDUCTION OF COMPUTATIONAL TIME

The most obvious disadvantage of using the Kalman filter compared with the constant gain alpha-beta filter is the increase in complexity and computation time required to compute this optimal gain schedule. There are several techniques which can be employed to reduce this burden, all of which result in further loss of optimality, but to limited extents.

In general, the R matrix is a function of the states or position of the aircraft. If the rough start and end points for the tracks to be followed are known in advance of the mission, it is possible to compute the average R, $\theta$, and $\phi$ and thus an average R matrix. Unless R, $\theta$, and $\phi$ vary over wide ranges, the loss in optimality by this approximation should be small. Since the gain schedule in state dependent only to the extent that R is state dependent, the gain schedule can now be computed and stored is a mission data table, and thus need not be computed on-line. Since 18 different gains are required by RADAR6 and 27 by RADAR9 for each sampling time, this becomes a rather large problem if auxillary storage is not available.

An alternative to storing the gain schedule is to fit each of the gain schedules to either an exponential curve or to a function of the type

$$f(x) = a + b\,x^{-1} + c\,x^{-2} + d\,x^{-3} + \cdots \qquad (64)$$

Then only 18 (or 27) computations would be required at each sampling time.

Whatever technique is chosen to approximate the true gain schedule, it will not be nearly as sub-optimal as a constant gain over all time, or two constants which are switched in and out.

# III. PRECISION GUIDANCE SIMULATION

## A. INTRODUCTION

A limited amount of Precision Guidance simulation program documentation was provided with the original version of the program. This greatly facilitated understanding of the original version of the program, and also subsequent modification for improvement. Many of the original concepts used were not changed. Input and output formats were revised for ease of use and to provide a greater indication of program performance. Since large portions of the original program's logic and coding have been retained, these may be mentioned and summarized lightly for continuity. The derivations and justification of assumptions in these areas will not be addressed, as they are considered to be adequately documented in the existing system documentation.

A block diagram of the simulation program control loop is presented in Fig. 4. In a few words, the program starts with the aircraft at some designated position and velocity with respect to a target which is to be bombed. After a 6 sec filter settling period, control logic determines the lateral error which will be incurred if the present flight profile is continued until time to release the bomb. Functions of the lateral error become the controlling mechanism to generate command bank angles which cause the aircraft to change course. It is emphasized that all control commands

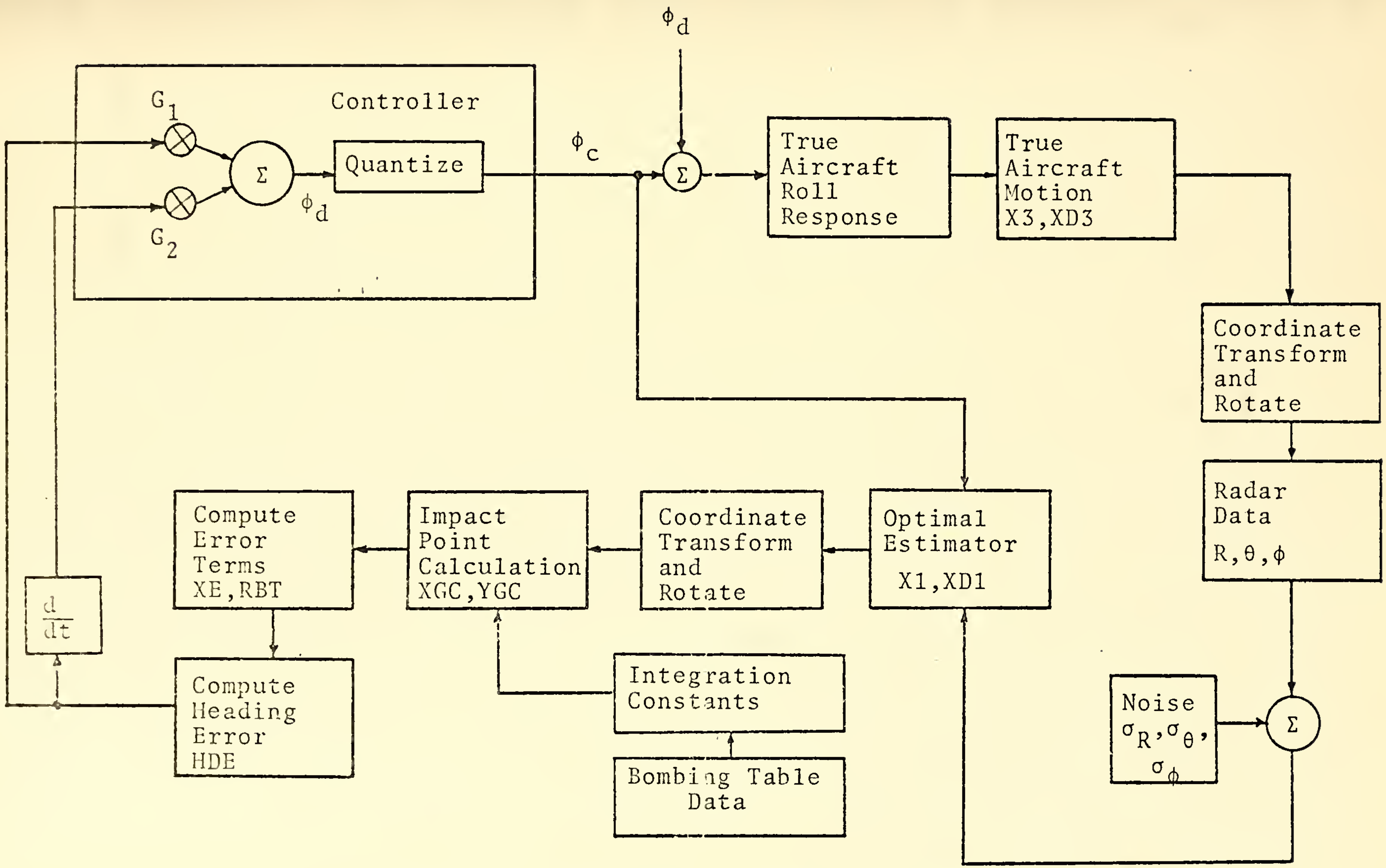



Figure 4. Simulation Program block diagram.

are based on estimated positions and velocities. Thus it may be possible to drive the estimated lateral error to zero, and still miss the target considerably, if the state estimation vector is in error. One further comment is that the problem is not totally one of estimation and control. The aircraft has a bank angle limitation imposed of ± 30 degrees. This limits the turning rate such that, depending on the initial position and velocity with respect to the target, the aircraft may not be physically able to come about to the correct heading in the time required. Examples of this situation are provided.

## B. INITIALIZATION AND FILTER SETTLING TIME

The new simulation program is functionally similar to the original version in initialization. The same variables are used wherever meaningful. The coordinate transformation vectors and matrices defined during initialization are retained, as are all equations for operating in the dive bombing mode. (The original program provided logic for executing a diving mode, but use of this mode has not been investigated in this study.)

The precision radar sampling rate is 8 Hz. No action except state estimation is taken during the first 2 sec of the simulation run. At the 2 sec point, logic is executed to enable prediction of the lateral error at 6 seconds into the run. The 4 second lag is assumed to be due to an attempt to simulate the fact that the actual computer used is compute-time limited, thus constraining the integration logic to

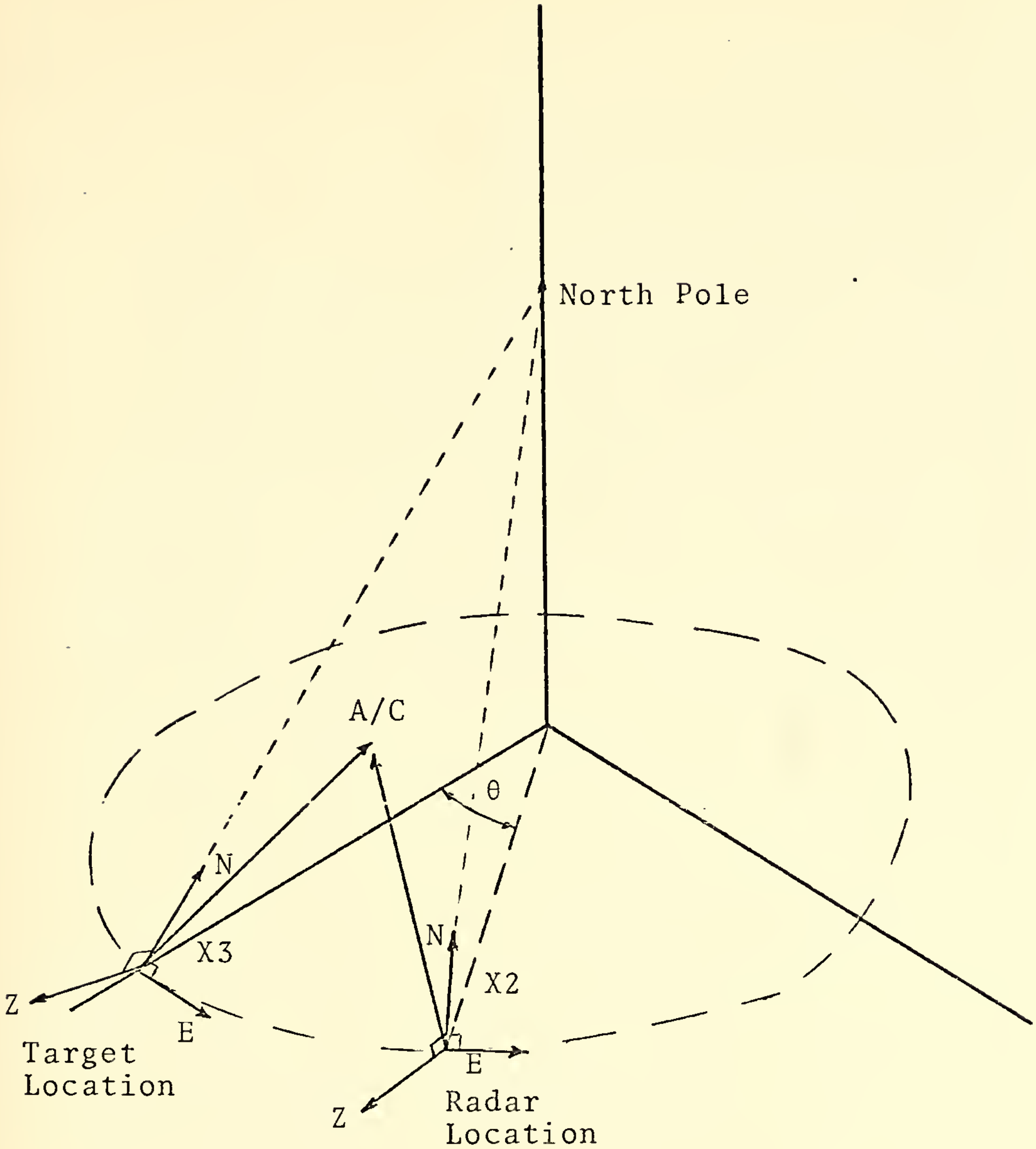
execution at no more than 0.25 Hz. At t = 6 seconds, the lateral error is first estimated, and the first non-zero command to the aircraft can be transmitted.

## C. PRECISION GUIDANCE COORDINATE CONVENTIONS AND TRANSFORMATIONS

Three primary coordinate systems are used in Precision Guidance calculations. These systems have their origins at the target, the radar, and the aircraft. A convention in notation is used throughout the program to denote vectors in the various coordinate systems. X1 represents a position vector, XD1 represents a velocity vector, and XDD1 represents an acceleration vector. (The only time acceleration vectors appear are in RADAR9.) The number "1" in the notation simply refers to a specific coordinate system.

X1 represents the state estimate of the aircraft in the radar reference frame; X2 represents the true state vector of the aircraft in the radar frame. X3 represents the state vector of the aircraft in the target frame. Conversion from one frame to the other is accomplished through the use of transformation matrices EM1, EM2, and EV1, and the subroutines MATMLT, and MATMAD which perform the matrix multiplication and addition. The relationship between X2 (or X1) and X3 is illustrated in Fig. 5.

Aircraft control is derived through the use of the X6 coordinate system, which has its origin at the aircraft and its y axis oriented along the estimated aircraft ground heading. This transformation is accomplished through the coordinate transformation matrix EM3. Figure 6 illustrates the




The local vertical is labeled Z. Local North is the y axis, and local East is the x axis in each frame. The dashed line is a great circle through the two points. Point labeled A/C is the aircraft.

Figure 5. Illustration of the relationship between the X3 and the X2 coordinate systems.

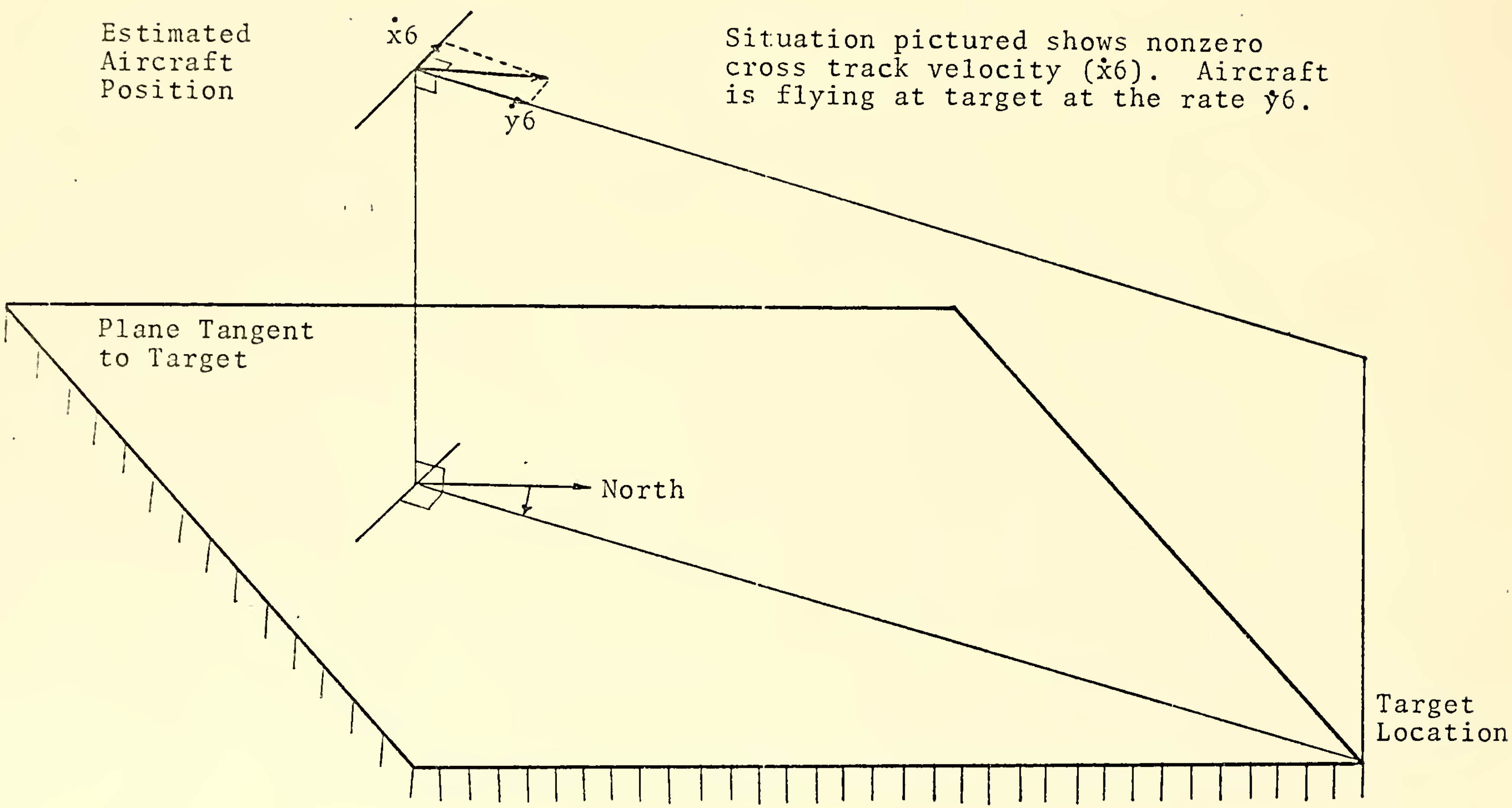



Figure 6. Illustration of relationship between X6 and the Target.

the relationship between this coordinate system and the target. Note that in the case of perfect estimation and no wind that this y axis orientation would point directly at the target.

Each of the X, XD, and XDD vectors are of dimension 3, one storage allocation for each physical dimension. Thus,

$$X1(1) = x1$$

$$X1(2) = y1$$

$$X1(3) = z1.$$

The coordinate systems and transformation equations are fully specified in [11].

## D. LOOP GEOMETRY AND ERROR CALCULATIONS

The normal flow of control through the main program loop following the initial 6 second settling period begins with a time update and a movement of the aircraft in accordance with the command bank angle generated at the previous time, all within the original subroutine ARCRFT. The true position is then transformed into the radar frame, noise added, and the new state vector estimated using the RADAR9 subroutine. The estimated state vector is then transformed into the X6,XD6 system, sometimes referred to as the "double primed" reference system in the original program documentation.

As mentioned previously, every 4 seconds the simulation program computes new coefficients which are used to calculate the ballistic range to the target, and bomb time of fall. This involves integration of a system of 16 differential equations using a fourth order Runge-Kutta scheme. The ballistic

range (RA) and time of fall for the bomb (TF) are computed using a first order linearized approximation to the system of equations described above at those times when no integration has been performed. Subroutines STIFF, DER, and OUT are used to perform the required calculations; these are completely specified in [10].

The ballistic range, RA, is the distance the bomb will impact from the present aircraft position. Time of fall, TF, is the time in seconds which will elapse between bomb release and impact. These values and the ballistic wind components in track and cross-track to the aircraft estimated heading determine the impact point for the bomb in X6 reference frame. The equations for this estimated impact point, (XGC,YGC), are as described in [11]. Figure 7 illustrates the geometry of the situation for the windless case. It is assumed that by selecting the bomb release time carefully, a near-zero error in impact on the y6 axis can be achieved. Only by having the aircraft heading precisely correct will the cross track impact error, called lateral error (XE), be zero as well.

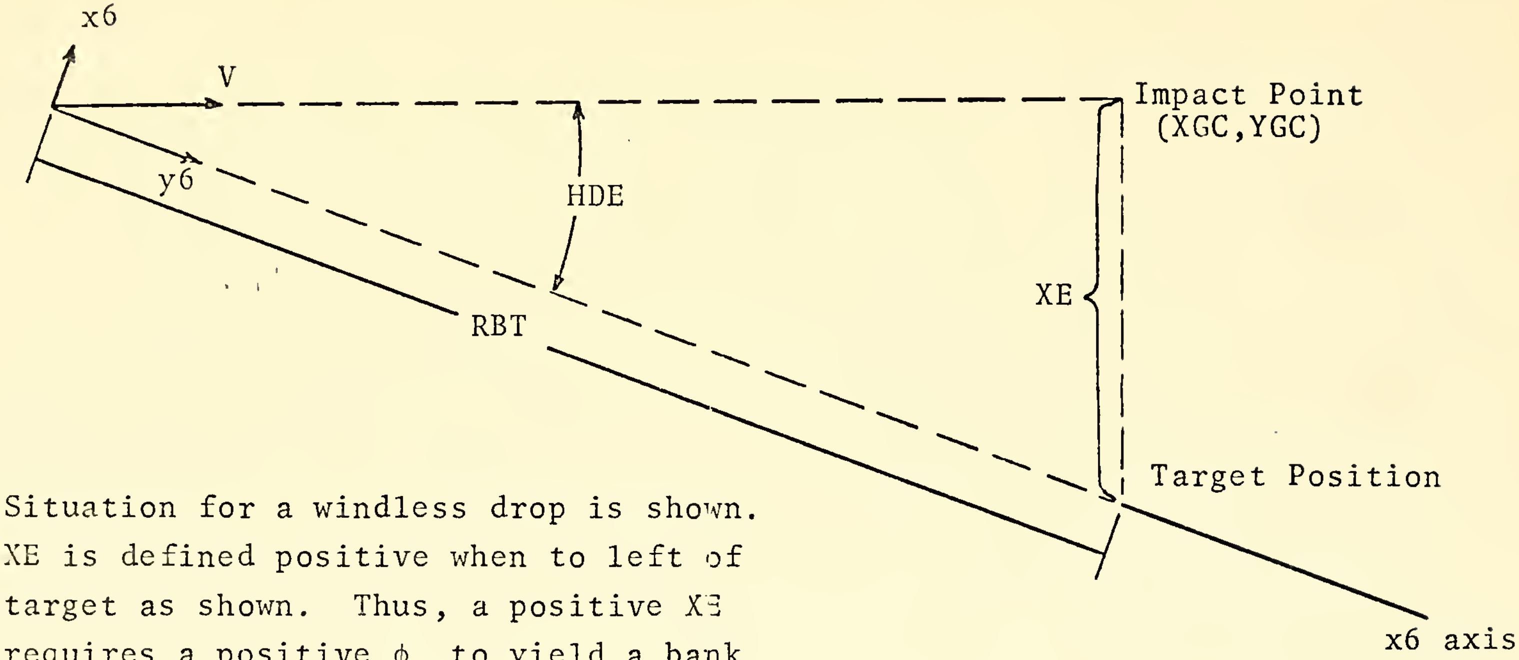
At each sampling point, the Time-to-Go-to-Release the bomb, TG, is computed using

$$TG = (y6 - YGC)/\dot{y}6 \ . \qquad (65)$$

The lateral error is given by

$$XE = x6 - XGC.$$

Other quantities which are used in error calculations are the ballistic range to the target, RBT, and the heading angle error, HDE. These are given by




Situation for a windless drop is shown. XE is defined positive when to left of target as shown. Thus, a positive XE requires a positive $\phi_c$ to yield a bank to the right.

Figure 7. Illustration of error and bombing geometry.

$$RBT = (x5^2 + y5^2)^{\frac{1}{2}} \tag{67}$$

where X5 is the coordinate system X6 prior to being rotated for heading-target alignment, and

$$HDE = \arcsin(XE/RBT). \tag{68}$$

## E. AIRCRAFT CONTROLLER DESIGN

The new controller for the aircraft is considerably less complex than that originally used. The original version employed lead-lag networks, suitably digitized, with constants which were switched in or out at different stages of the simulation run. The lateral error was driven to zero in the original version of the program, by selection of a gain constant times the lateral error to yield a desired bank angle.

The new controller design attempts to drive both an error and an error rate to zero. The error signals to be driven to zero are the heading angle error, HDE, and the heading angle error rate, HDEDOT, where

$$HDEDOT = \dot{HDE}. \tag{69}$$

The desired control bank angle, $\phi_d$, is given by

$$\phi_{d1} = G_1 \text{ HDE} \tag{70}$$

$$\phi_{d2} = G_2 \text{ HDEDOT} \tag{71}$$

and

$$\phi_d = \phi_{d1} + \phi_{d2}. \tag{72}$$

This procedure requires selection of the feedback gain constants $G_1$ and $G_2$. It should be noted at this time that $G_1$ and $G_2$ are the only two constants in the simulation program which must be determined "through simulation," i.e., by

trial and error. The original program was filled with numerous "gain constants" which were, or were to have been selected by "simulation." In addition, in the original version, much of the theory was developed through the assumption that the process was approximately a linear one, and development of a linearized model which reflected these linearizations. Such linearization may be somewhat valid in the final stages of a long run where only small commands are being sent, but in the initial phase of heading correction, the commands saturate and the assumption of linearity is invalid. It is in this nonlinear region of operation that commands must be optimized to yield a combination of rapid correction of heading error and minimum overshoot of the correct heading.

Two sets of control gains have been selected for the two prevalent aircraft roll response time constants, $\tau_b = 2$ and $\tau_b = 3.3$. The gain constants are given below.

$$\tau_b = 2 : \quad G_1 = G_2 = 75$$

$$\tau_b = 3.3 : G_1 = G_2 = 150.$$

These parameters were selected through analysis of numerous simulation runs with each $\tau_b$ and subjectively evaluating the resultant performance. The performance criteria used was to generate initial commands which are of the "bang-bang" type referred to in optimal control theory, causing the bank command to saturate at the autopilot limit of ± 30 degrees. This causes the aircraft to begin turning toward the correct heading at the maximum possible rate permitted. The effect

of heading error rate control is to act as a damper in that the faster the heading angle changes, the more the control will begin to decrease. The second part of the performance criteria was to require that when small angle errors are noted, only small commands are generated.

There is a requirement for no bank commands during the final second of flight. This is to ensure that the aircraft does not make a violent maneuver just as the bomb is dropped, causing the bomb to be pitched from the aircraft rather than simply dropped as had been assumed in the bombing calculations.

For a one second period beginning three seconds before bomb release, i.e., TG = 3 to TG = 2, the average estimated aircraft bank angle is computed. This average estimated bank angle is then sent as the command during the final two seconds before bomb release. The reason for sending this value vice a command of zero degrees is the possible presence of a bias angle. Figure 8 is a plot of a typical simulation run in which the autopilot has a bias bank angle of 3 degrees. Note that this bias is automatically compensated for by the commands sent. The average command at the end of the run is approximately -3 degrees. This has the effect of rolling the aircraft back to a level flight profile in a steady-state situation, vice a slowly turning profile which would be present if the command was 0 degrees. By averaging the estimated bank angle over the period defined above, and sending this value for the final few seconds, the aircraft continues on an approximately error free path. A zero command

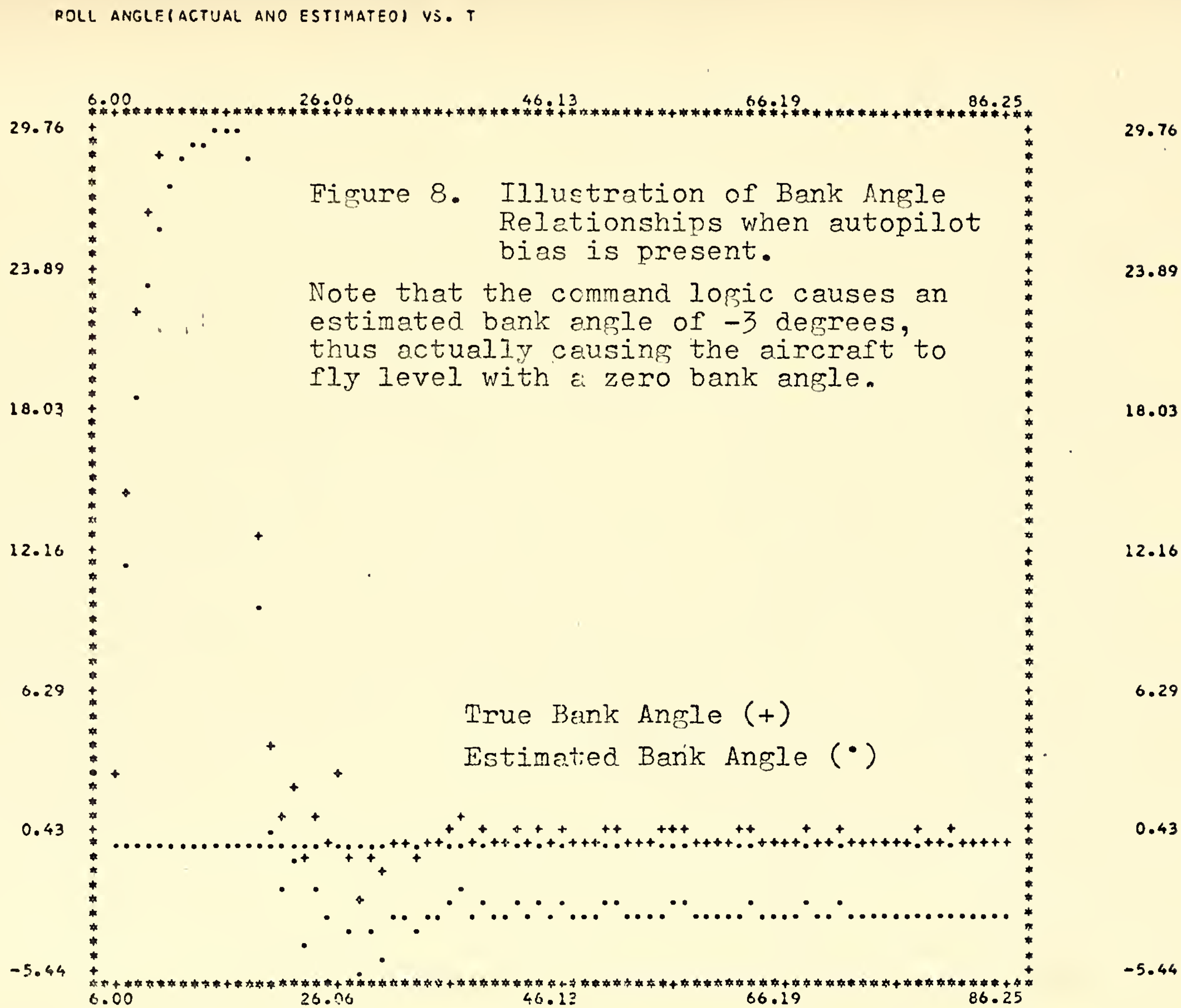



Figure 8. Illustration of Bank Angle Relationships when autopilot bias is present.

Note that the command logic causes an estimated bank angle of -3 degrees, thus actually causing the aircraft to fly level with a zero bank angle.

at this time would cause the aircraft to begin a slow turn and greatly increase the lateral error with no opportunity for correction.

Command system requirements require that the command angle be quantized to the nearest 15/128 degree. This is accomplished through simple logic as described in [11].

## F. PRECISION GUIDANCE PROGRAM IMPLEMENTATION

### 1. Main Program and Subroutines

The Precision Guidance simulation program consists of a main routine and seven primary subroutines. The program listing is appended at the end of this report. Each of the subroutines is included and in each of the routines the primary variables and purpose of the routine is specified, with the exception of subroutines STIFF, DER, and OUT, which serve only to support the Runge-Kutta integration defined above. The simulation program was written to run on an IBM 360-67 computer system and takes advantage of several of the system software subroutines. The program with linkage and subroutines requires approximately 150 K to execute and will run a typical time of from one to three minutes of CPU time. Compilation requires approximately 50 seconds.

A listing of the variables used in the program along with the variable definitions is provided in Appendix A.

### 2. Program Input and Output

Specific format definitions for program input data are provided in Appendix B. The program output has been

changed significantly from that in the original program version. A sample of one complete simulation run is provided at the end of this report. The initial conditions and constants are output along with short word definitions of their meaning or useage. Each second, a summary of the critical parameters of the program are output in block form; the output key is printed on each page for ready availability to the user. During the final second before bomb release, the critical parameters summary is printed at every sampling point.

On the final time through the main processing loop, all estimates are replaced by their corresponding true values, and the bomb "released." The impact point is computed, and the miss distances in x,y and overall are printed, designated XI, YI, and RI, respectively.

As a measure of filter effectiveness in noise reduction and state prediction in position including deterministic motion, the square of filter residual is summed throughout the run. The RMS values of filter residue are printed following the bomb impact miss distances. Filter residue in this sense is defined as

$$FILRES_x = x1 - x2 \tag{73a}$$

$$FILRES_y = y1 - y2 \tag{73b}$$

$$FILRES_z = z1 - z2. \tag{73c}$$

In addition to the filter residual in each coordinate, a radial residual defined as

$$FILRES_R = (FILRES_x{}^2 + FILRES_y{}^2 + FILRES_z{}^2)^{\frac{1}{2}} \tag{74}$$

is printed in RMS form, where the average is over the entire simulation run.

Some of the critical parameters are stored in arrays each second throughout the run. These are then line printer plotted at the completion of the run with appropriate labelling.

# IV. COARSE GUIDANCE SIMULATION

## A. INTRODUCTION

Two documents, [8] and [9], were provided to describe the techniques and general approach being followed on the original Coarse Guidance simulation program. However, no program documentation such as that provided for Precision Guidance, [11], was available. The program provided seemed inordinately complex in some places and the general approach to the problem did not appear to be a viable one from which to build an improved version.

It was determined that the best approach would be to write a totally new main simulation driving routine, use the already existing aircraft simulation program, ARCRFT, and the already developed Kalman filter radar simulation program RADAR6 to simulate the Coarse Guidance tracking system. RADAR6 was chosen vice RADAR9 simply because neither [8] nor [9] mentioned any difficulty with bank angle biasing. Also, the smaller size and faster running time of RADAR6 made that subroutine a preferred choice. The decision to mate RADAR6 to Coarse Guidance rather than RADAR9 is by no means a final choice. A matter of only a few minutes would be required to modify RADAR9 to be compatible with the Coarse Guidance simulation program. Thus if biasing is a problem in this mode also, RADAR9 could serve as the appropriate unbiased state estimator. The changes in RADAR6 from RADAR9 other than those which relate to acceleration estimation will be discussed

below. A few simplifying changes in the ARCRFT subroutine were also accomplished to reduce core storage requirements and execution time; these will also be described.

Some of the concepts and a few equations from the original documents on Coarse Guidance were used in this study. Since the new simulation program differs significantly from the original version, nearly all equations will be presented and most will be derived.

The basic concept in Coarse Guidance is to get the aircraft from some initial starting point to the final bombing run by flying a predetermined course which is specified by "waypoints" and azimuths of course "legs." A typical simulation setup might appear as illustrated in Fig. 9. The designated legs presumably follow a "safe" path for the strike aircraft. Also, presumably, if the aircraft deviate from the specified path too far, they become in danger. Therefore, it is desirable to provide some control to keep the aircraft as near to the specified path as possible. Of particular importance is to recognize the approach of the beginning of a new leg and begin a "command turn" onto this new leg at such a time that upon completion of the turn, the aircraft will be on the new leg with the same ground heading as the leg's azimuth.

## B. PRE-MISSION DATA TABLE COMPUTATIONS AND INITIAL CONDITIONS

Once the path to be flown is specified, the individual legs can be characterized by their azimuth with respect to North and their length. The beginning of the mission is

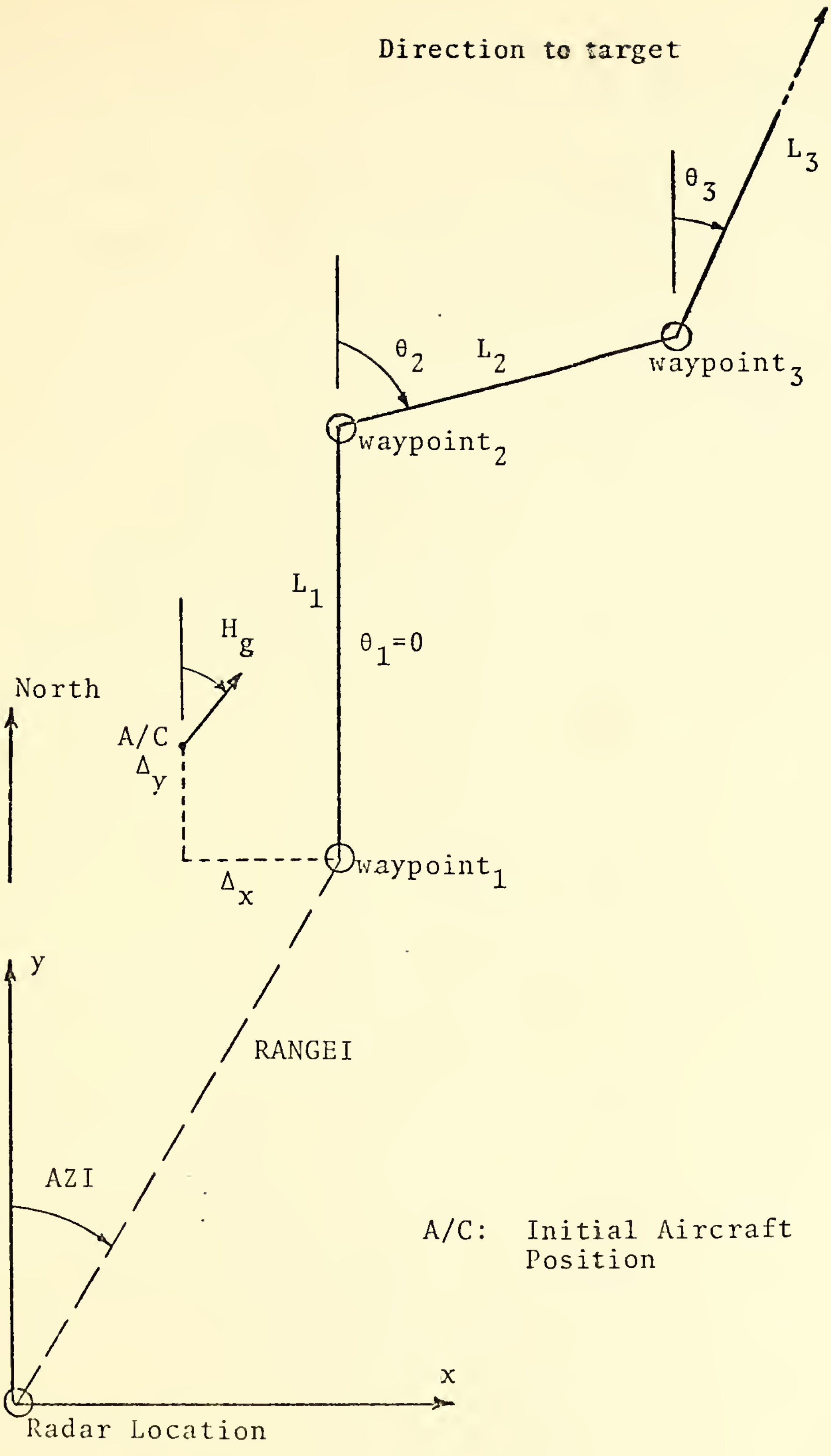



Figure 9. Illustration of a typical 3 leg course.

referred to as a TACAN Entry Point, and is the approximate position of aircraft entry into the problem. Wind causes the ground heading and the air heading to differ. Since most of the aircraft control calculations are made with respect to the air heading, effects of wind must be considered. The initial position of the aircraft is placed at the beginning of the first leg perturbed by some error, and with ground heading of the first leg's azimuth also perturbed by some angle deviation from desired.

1. True and Estimated Wind Components

Figure 10 illustrates the relationship assumed for wind in the problem. Provision is made for an error in estimated wind speed and direction. All true aircraft motion is computed using true wind. All estimated aircraft motion and control decisions are made using the estimated wind components. Wind is assumed zero in the vertical direction. If the true (estimated) direction toward which the wind is blowing is $\theta_w$ ($\theta_{wh}$), and the true (estimated) wind speed is $V_w$ ($V_{wh}$) then the components of wind are given by

$$w_x = V_w \sin(\theta_w) \tag{75a}$$

$$w_y = V_w \cos(\theta_w) \tag{75b}$$

for the true wind, and

$$w_{xh} = V_{wh} \sin(\theta_{wh}) \tag{76a}$$

$$w_{yh} = V_{wh} \cos(\theta_{wh}) \tag{76b}$$

for the estimated wind.

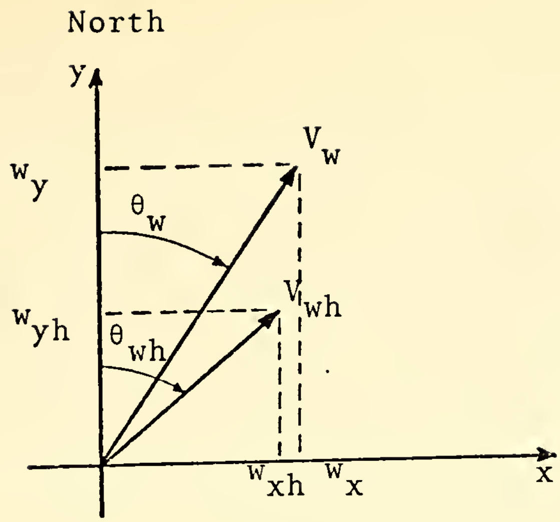



Figure 10. Illustration of Wind Relationships.

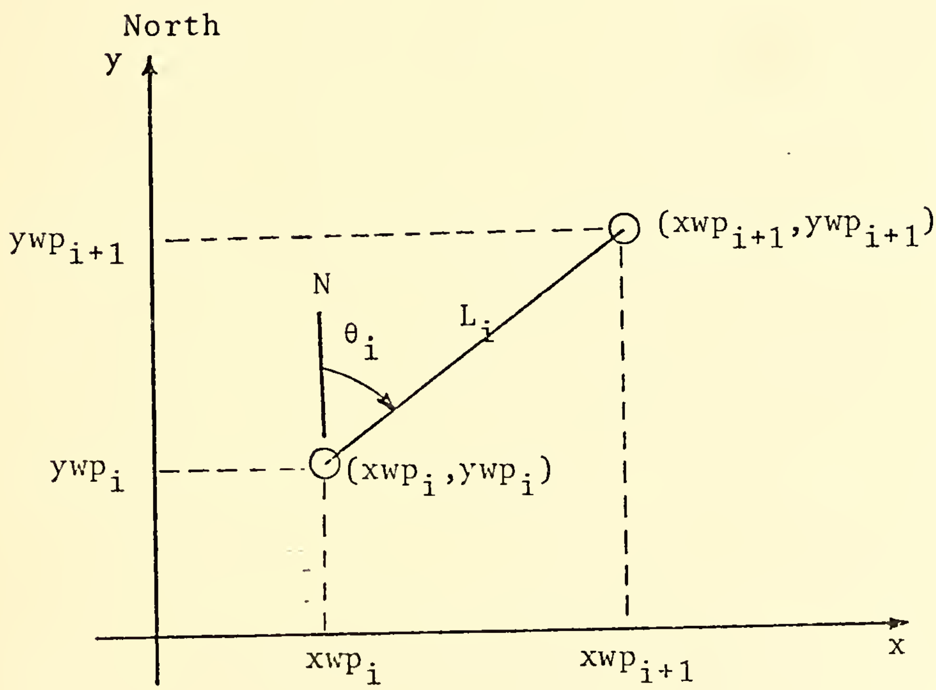



Figure 11. Illustration of Waypoint Coordinate Calculations.

## 2. Mission Data Table Calculations

Included in the mission data table are the waypoint coordinates, average radar range to each leg, average radar azimuth to a given leg, desired air heading while on each leg, desired ground speed while on each leg, approximate time to fly each leg, and the ground velocity components for each leg.

For notational purposes, it is assumed that there are a total of n legs to be flown; a subscript i on any parameter indicates that parameter for the $i^{th}$ leg. Figure 11 illustrates calculation of the i+1 waypoint coordinates from the previous leg's parameters. If $(xwp_i, ywp_i)$ are the coordinates of the $i^{th}$ waypoint, the azimuth of the $i^{th}$ leg is $\theta_i$, and the length of the $i^{th}$ leg is $L_i$, then

$$xwp_{i+1} = xwp_i + L_i \sin(\theta_i) \tag{77a}$$

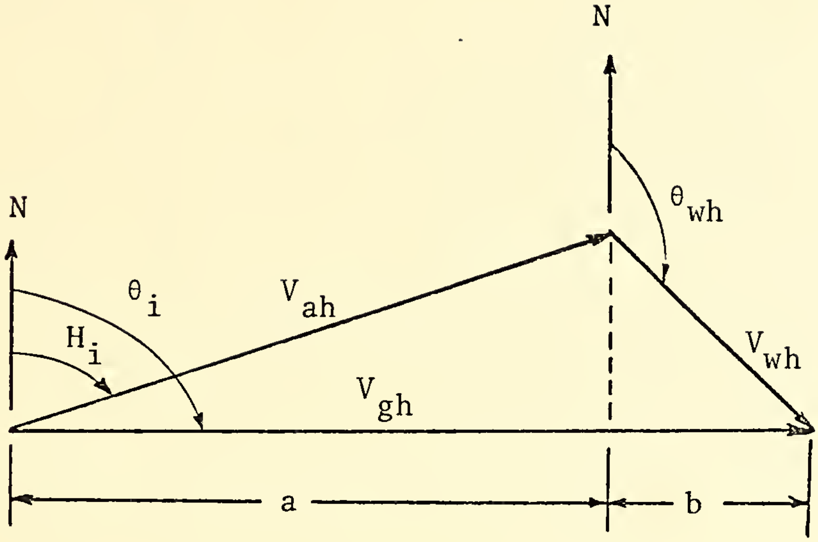
$$ywp_{i+1} = ywp_i + L_i \cos(\theta_i). \tag{77b}$$

The average range and azimuth to the $i^{th}$ leg, $R_i$ and $Az_i$ are given by

$$R_i = \tfrac{1}{2}[(xwp_i+xwp_{i+1})^2 + (ywp_i+ywp_{i+1})^2]^{\frac{1}{2}} \tag{78}$$

$$Az_i = \arctan\left[\frac{xwp_i + xwp_{i+1}}{ywp_i + ywp_{i+1}}\right]. \tag{79}$$

Figure 12 presents geometry which aids in clarifying calculation of the air heading and ground speed, assuming the air speed is a known constant. (This assumption is maintained through the problem and seems reasonable, since




$$a = V_{ah} \cos(H_i - \theta_i)$$

$$b = V_{wh} \cos(\theta_{wh} - \theta_i)$$

Figure 12. Illustration of Ground Speed and Air Heading Calculation Geometry.

the pilot has a direct readout of his speed with respect to the air.) Since it is desired to fly along the leg, it is correct to sum components perpendicular to the leg and set these to zero. If $V_{ah}$ is the estimated air speed and $H_i$ is the air heading then

$$V_{ah}\sin(H_i - \theta_i) + V_{wh}\sin(\theta_{wh} - \theta_i) = 0. \qquad (80)$$

Summing components in the direction of the leg yields the desired ground speed

$$V_{gh} = V_{ah}\cos(H_i - \theta_i) + V_{wh}\cos(\theta_{wh} - \theta_i) \qquad (81)$$

$V_{gh}$ can be broken into Cartesian components, $V_{gx}$ and $V_{gy}$ as follows:

$$V_{gx} = V_{gh}\sin(\theta_i) \qquad (82a)$$

$$V_{gy} = V_{gh}\cos(\theta_i). \qquad (82b)$$

The air heading required to fly in the direction $\theta_i$ is found by solving (80) for $H_i$.

$$H_i = \theta_i - \arcsin\left[\frac{V_{wh}}{V_a}\sin(\theta_{wh} - \theta_i)\right]. \qquad (83)$$

3. <u>Initial Position and Velocity of the Aircraft</u>

The initial true position of the aircraft is that of the first waypoint plus a perturbative error. Since the waypoint is on the ground, the altitude of the aircraft is given by the perturbation in the z coordinate. The true position of the aircraft is contained in the X array.

$$x3 = xwp_1 + \Delta_x \qquad (84a)$$

$$y3 = ywp_1 + \Delta_y \qquad (84b)$$

$$z3 = \Delta_z. \qquad (84c)$$

The initial true ground heading, $H_g$, is read as data. This in addition to the known airspeed, $V_a$, specifies the true ground speed, $V_g$, and the true air heading, $H_a$, through a set of equations similar to (80), (81), and (83). The results are given by

$$H_a = H_g - \arcsin\left[\frac{V_w}{V_a} \sin(\theta_w - H_g)\right] \tag{85}$$

and by

$$V_g = V_a \cos(H_a - H_g) + V_w \cos(\theta_w - H_g). \tag{86}$$

The initial true velocity of the aircraft is then broken into Cartesian coordinates and stored in the XD3 array.

$$\dot{x}3 = V_g \sin(H_g) \tag{87a}$$

$$\dot{y}3 = V_g \cos(H_g) \tag{87b}$$

$$\dot{z}3 = 0. \tag{87c}$$

Note that it is through specification of $H_g$ different from $\theta_1$, and $\Delta_x$ and $\Delta_y$ different from 0 that nonzero perturbations in velocity and position from the desired values are entered. Figure 9 also shows the geometry which might exist in the case of nonzero displacement and velocity from the desired track.

## C. AIRCRAFT POSITION, VELOCITY, AND ERROR ESTIMATION

As previously stated, aircraft motion is simulated by the use of a slightly modified version of subroutine ARCRFT associated with Precision Guidance. Position and velocity estimation is accomplished using RADAR6. At the beginning of

the main processing loop, true aircraft position is updated followed immediately by a prediction update on estimated aircraft position. A new estimation update is performed only if the total radar sampling interval DTRAD has ellapsed. (It is assumed that prediction updates occur at a higher rate than radar sampling.) The most current aircraft position and velocity estimates are contained in the X1 and XD1 arrays. From this and the estimated wind components, the estimated air and ground headings, and estimated ground speed are computed; $H_{ah}$, $H_{gh}$, and $V_{gh}$, respectively.

$$H_{gh} = \arctan\left[\frac{\dot{x}1}{\dot{y}1}\right] \tag{88}$$

$$H_{ah} = \arctan\left[\frac{\dot{x}1 - w_{xh}}{\dot{y}1 - w_{yh}}\right] \tag{89}$$

$$V_{gh} = (\dot{x}1^2 + \dot{y}1^2)^{\frac{1}{2}}. \tag{90}$$

These parameters can be monitored to determine the degree of error in heading and speed from the desired values. An additional and important parameter to be monitored is the extent to which the aircraft has deviated from the desired course, $E_{est}$. Figure 13 illustrates the geometry used in this calculation. The error is given by

$$E_{est} = (x1 - xwp_i)\cos(\theta_i) - (y1 - ywp_i)\sin(\theta_i). \tag{91}$$

Note that (91) computes the distance from the present position estimate to the leg i. In a command turn, the aircraft should not be on either leg, but will be somewhere between

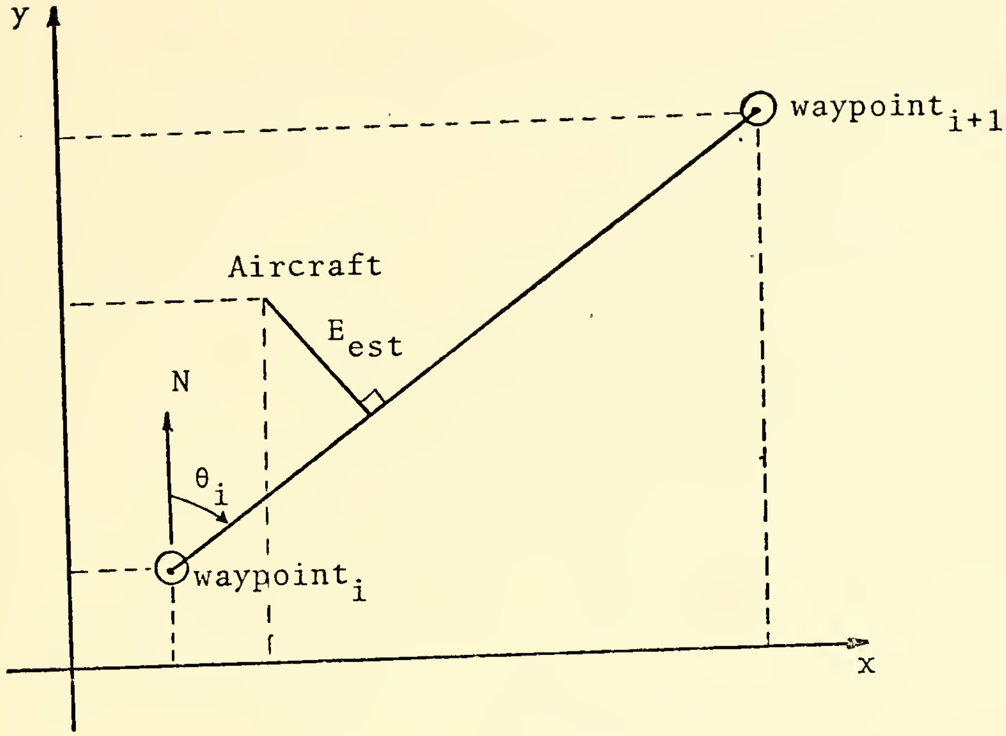



Figure 13. Illustration of Geometry for Calculating Deviation from the Desired Leg Path.

the legs. For this reason, distance from both the $i^{th}$ and i+1 leg is computed, and the smaller of the two values chosen.

True headings, speeds, and distances corresponding to those given above are also computed using the same equations with X3 substituted for X1, and W substituted for $W_h$.

## D. COMMAND TURN CALCULATIONS

The command turn is that which is computed to cause a smooth transition of the aircraft from the present leg to the next leg with a minimum or overshoot or undershoot of the desired path. The aircraft autopilot is constrained to a maximum bank angle, $\phi_m$, typically equal to 30 degrees. Since the heading angle rate is proportional to the bank angle in a coordinated turn, the time to complete the turn using the maximum possible bank must be precalculated so that the turn can be started prior to reaching the new leg. This process is complicated by three factors. The first is that the time to the next leg is variable with the current position and velocity. Thus the time to begin the turn as well as the amount of heading change required is a function of the state estimate. The second factor is that the equation to be solving for the amount of time required for the turn is a transendental equation and must be solved through iteration. The third factor is that this equation becomes unduly complex if the turn is not started from a zero bank angle. This requires that the aircraft begin the turn in level flight.

### 1. Time Remaining on Present Leg

The time remaining on the present leg before intersecting with either the next leg or its extension is computed by finding the intersection of the two paths, calculating the distance to be traversed, and then dividing by the estimated ground speed. The geometry is illustrated in Fig. 14.

The coordinates of intersection of the present path, based on the present velocity estimate and the next leg are designated $(x_{int}, y_{int})$. Let $m_i$ and $m_{i+1}$ represent the slopes of the present aircraft heading and the next leg, respectively. Then

$$m_i = \dot{y}1/\dot{x}1 \tag{92}$$

$$m_{i+1} = (ywp_{i+1} - ywp_i)/(xwp_{i+1} - xwp_i). \tag{93}$$

The equations of the two lines whose intersection is to be found are

$$y = m_{i+1}\,x - (m_{i+1}\,xwp_{i+1} - ywp_{i+1}) \tag{94}$$

$$y = m_i\,x - (m_i\,x1 - y1). \tag{95}$$

These equations are solved simultaneously to give the point of intersection.

$$x_{int} = \frac{(y1 - ywp_{i+1}) + (m_{i+1}\,xwp_{i+1} - m_i\,x1)}{(m_{i+1} - m_i)} \tag{96}$$

$$y_{int} = m_i\,x_{int} - m_i\,x1 + y1. \tag{97}$$

The distance between x1 and the point of intersection is then

$$D_{tg} = [(x_{int} - x1)^2 + (y_{int} - y1)^2]^{\frac{1}{2}} \tag{98}$$

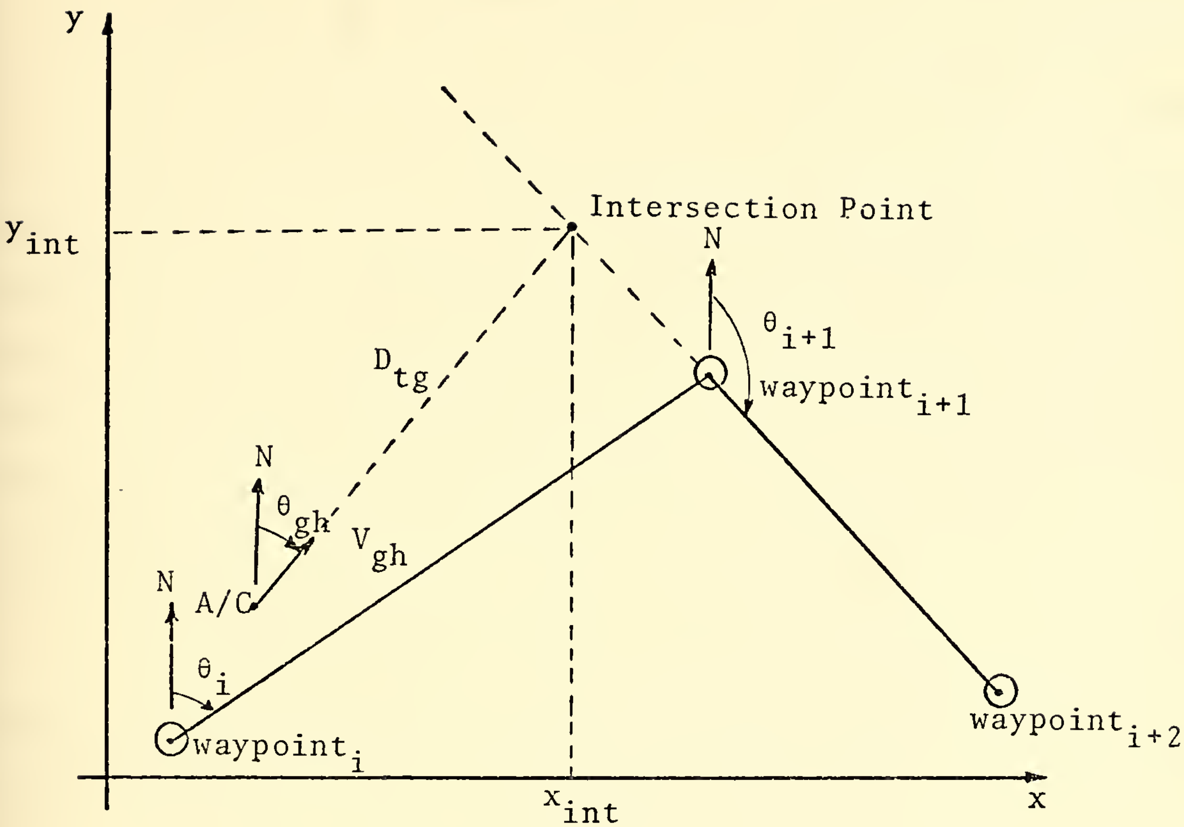



Figure 14. Illustration of Path-Leg Intersection Geometry.

and the time to reach this point is given by

$$TLEG1 = D_{tg}/V_{gh}. \tag{99}$$

2. Time Required to Complete the Turn

The amount of turn required, $\Delta H$, is simply

$$\Delta H = |H_{i+1} - H_{ah}| \,. \tag{100}$$

Air headings are used in the calculations since all aircraft motion and turn equations must account for the possible presence of wind. Equation (50) gives the relationship between the change in heading angle, time in the turn, and the roll response of the aircraft. Setting $\Delta\psi$ equal to $\Delta H$ and $\phi_c$ equal to $\phi_m$ gives

$$\Delta H \doteq (g/V_{ah})\left[\phi_m T + (\phi(k-1) - \phi_m)(\tau_b)(1 - e^{-T/\tau_b})\right]. \tag{101}$$

If it is assumed that $\phi(k-1)$ is zero (starting with level flight), then the equation can be rewritten as

$$K \doteq U - (1 - e^{-U}) \tag{102}$$

where

$$U = T/\tau_b \tag{103}$$

and

$$K = \frac{\Delta H\ V_{ah}}{g\ \tau_b\ \phi_m} \,. \tag{104}$$

For the purpose of finding the turn time required, assume that the turn can be divided into three parts as illustrated in Fig. 15. The first part is the transient period during which the aircraft is coming to the maximum (or minimum) bank angle, going to that limit exponentially with time constant

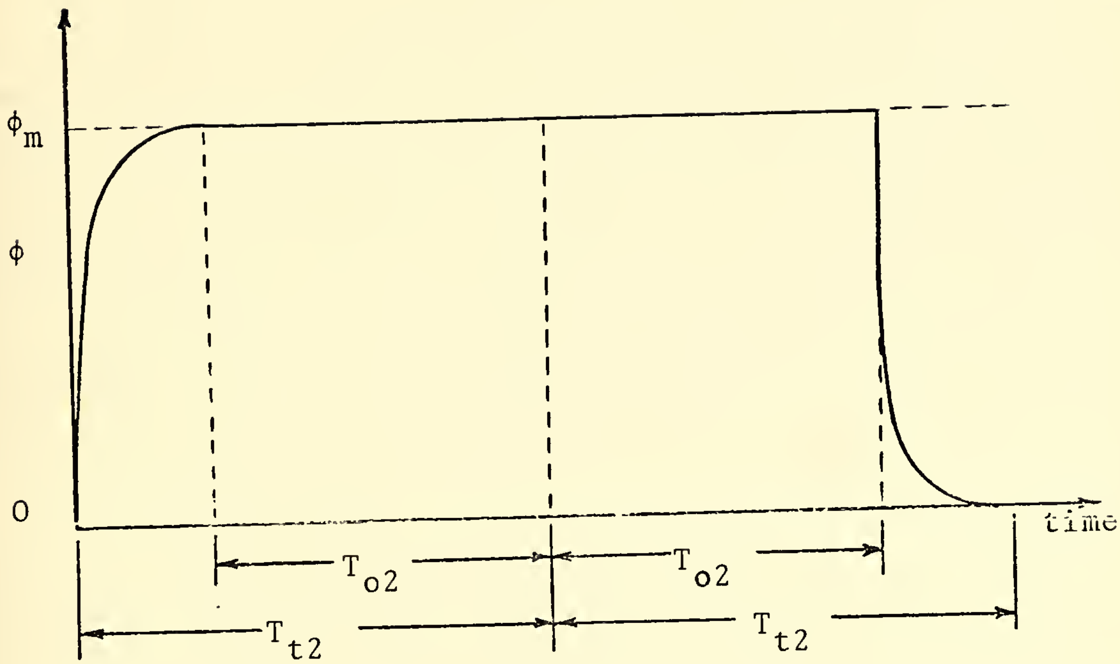



Figure 15. Illustration of Relationships Between Times and Bank Angles in a Command Turn.

$\tau_b$. The second part of the turn is that segment when the aircraft is holding at the bank limit and changing direction with an approximately constant heading rate. The third and final part of the turn is a transient segment during which the aircraft returns to a zero bank angle, also exponentially.

Figure 15 shows that the turn can be divided into two approximately equal parts, during which the aircraft executes approximately half of the turn, $\Delta H/2$. Let the time required to complete half of the turn be $T_{t2}$, and the time to complete half of the constant bank segment of the turn be $T_{o2}$. If K, above, is replaced by K/2, then the solution to (102) yields

$$U = T_{t2}/\tau_b. \tag{105}$$

The equation is solved using the Newton-Raphson iterative technique. The initial approximation to $T_{t2}$ is taken from [9]. Iteration continues until the change in $T_{t2}$ is less than 0.01.

Motion of the aircraft through the turn is approximated in nearly the same manner as described in [9]. Briefly, it is assumed that the aircraft continues on an approximately a straight path for a period $T_{t2}-T_{02}$ seconds after the command turn is ordered, followed by the command turn as described above, followed by another period of approximately straight flight along the new leg during the final seconds of the turn. A diagram of the geometry of the turn is presented in Fig. 16. Since the turn has been computed with respect to the motion of the air mass, movement of the air mass during the turn is

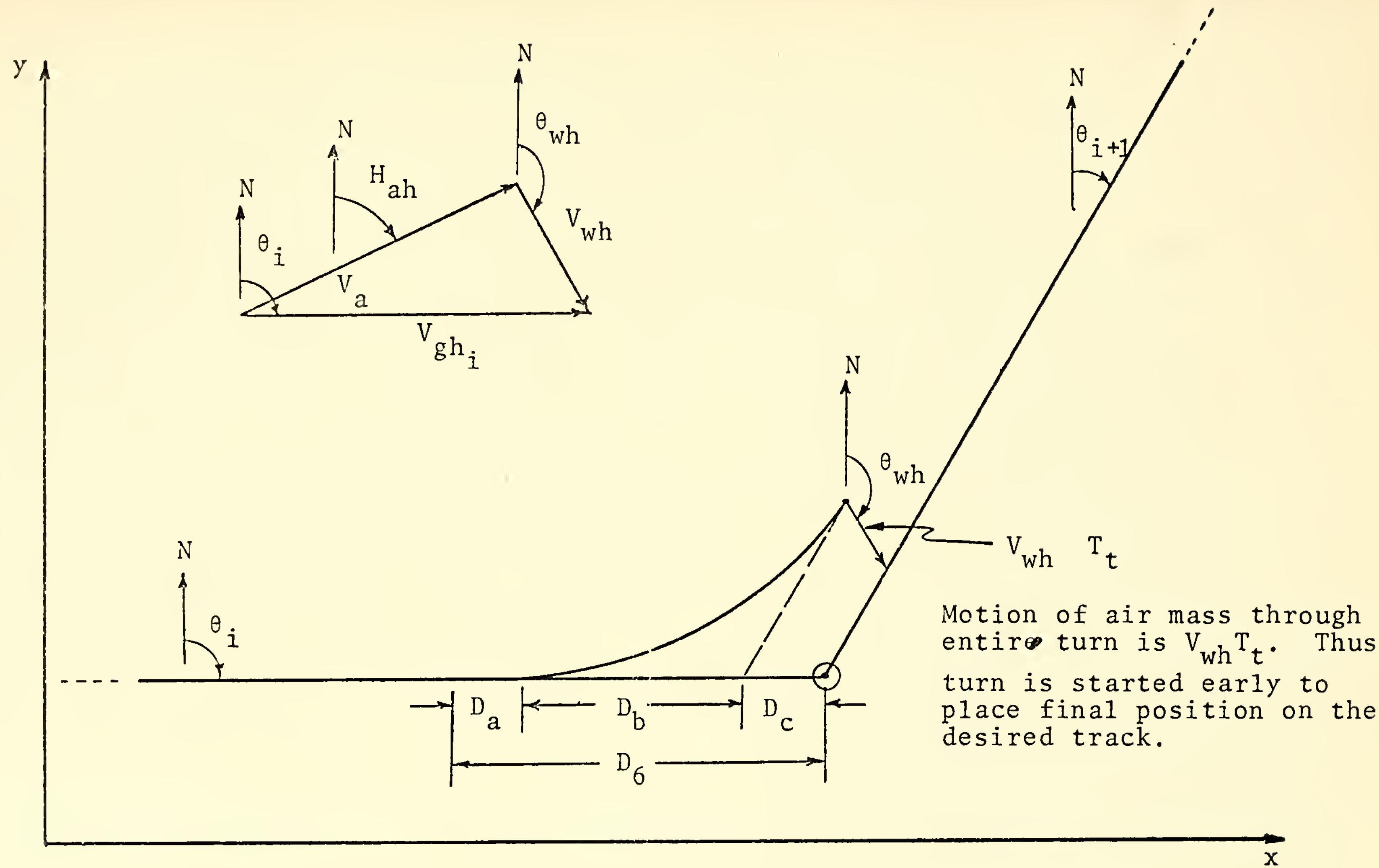



Figure 16. Illustration of Turn Geometry, Including Effects of Wind Shifting the Final Aircraft Position.

compensated for. The only modified equation used to calculate the distance prior to leg intersection from which the turn must start is that which relates to air mass motion. The new equation for computation of the parameter $D_c$ is given correctly by

$$D_c = T_{o2} V_{wh} \sin(\theta_{i+1} - \theta_{wh}) \sin(\theta_{i+1} - \theta_i). \quad (106)$$

The turn must be started a distance $D_6$ before the intersection with the next leg, where $D_6$ is shown on the illustration and mathematically defined adequately in [9].

3. Command Turn Timing Logic

The time-to-go before beginning a command turn is given by

$$TG = TLEG1 - D_6/V_{gh}. \quad (107)$$

When TG is less than or equal to zero, the aircraft is commanded to go to the maximum bank angle, with the sign of the bank chosen appropriately. The time to command the bank angle back to zero is $T_{stoptn}$ and is given by

$$T_{stoptn} = T_t - 2\tau_b. \quad (108)$$

Initially it might appear that $3\tau_b$ should be subtracted from the total turn time, since that would be closer to the amount of time required to decrease the full bank angle when the change is occurring exponentially. However, this value was arrived at through simulation trials, and is probably best due to the compounded approximations made in the overall turn solution. The time at which the turn is complete is defined as $T_t$; no actions depend on this time.

Figure 17 is a logic flow chart of the start/stop turning process. Briefly, a counter in the form of the variable TINTRN is incremented each time through the loop as the turn progresses. The variable ITURN is used as a flag to pass logical control to the correct coding. When no turn is in execution, ITURN = -1, and the only turning which is performed is that to correct the course deviations. No control banking for the above purpose is permitted within the $3\tau_b$ seconds prior to executing a command turn. This is to ensure that the bank angle of the aircraft is zero when beginning the command turn, an assumption which was used in the derivation of the command turn equations. During the command turn, ITURN = 0, and all control logic is bypassed. Immediately upon executing the logic which indicates the turn is ending, ITURN = 1, and calculations to check for the next turn time begin. If required, a new command turn can be executed immediately, before the aircraft has come down from its bank from the previous turn. This feature was added to ensure that if a short leg or a very acute turn was encountered, the best possible flight trajectory would be flown. Examples of the requirement for this feature and its performance are included.

## E. AIRCRAFT CONTROLLER DESIGN

The controller, used to guide the aircraft to a desired velocity and keep it there until a command turn, is of the same type used in Precision Guidance. In this case, the controller attempts to keep the estimated ground heading, $H_{gh}$,

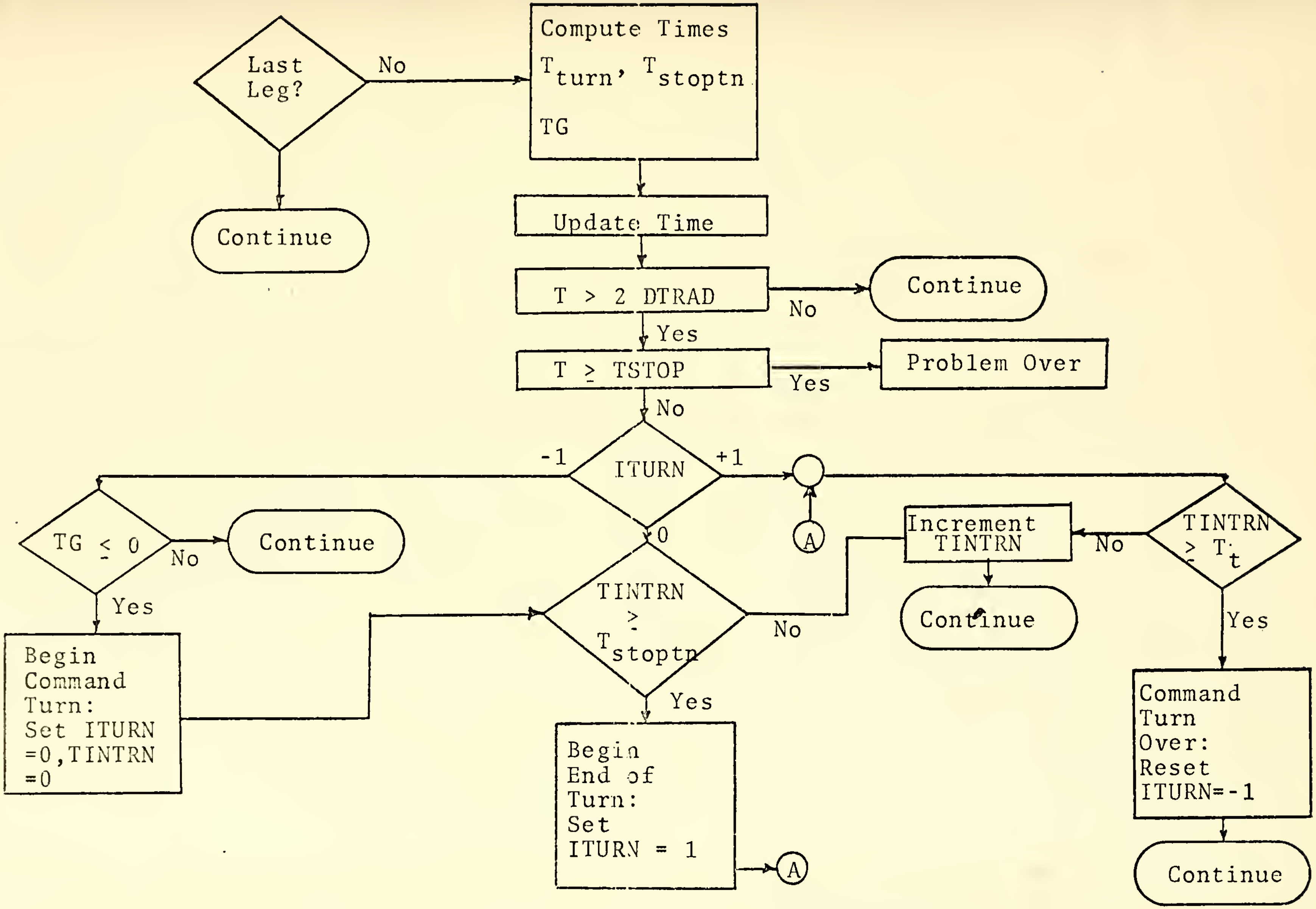



Figure 17. Command Turn Start and Stop Logic.

at that heading from the current estimated position which will fly the aircraft directly at the next waypoint. This scheme was selected for two primary reasons. The first is that it requires minimal control to get the heading correct and thus requires considerably less updating than the technique used in the original simulation program. The second reason is that this technique tends to avoid the problem of oscillation which plagued the original scheme. The controller features a technique which will block any command updates to the aircraft unless the heading error exceeds some minimum error angle, $H_{ermin}$.

The estimated heading to the next waypoint is

$$H_{hgwpt} = \arctan\left[\frac{xwp_{i+1} - x1}{ywp_{i+1} - y1}\right] . \tag{109}$$

The heading error is then

$$HDE = H_{ghwpt} - H_{hg} \tag{110}$$

and the heading error rate, HDEDOT is the discrete derivative of (110). These are combined as given in (70), (71), and (72) to give the desired control angle. The gains $G_1$ and $G_2$ were selected equal, as before, with the value 4. Different feedback gains were used in a number of simulation runs, and the results indicated that the system was somewhat insensitive to the values chosen. The gains yielded desired commands of about 20 degrees during normal course corrections, and with the $H_{ermin}$ feature seemed to avoid the undesired oscillation for the most part.

The commands are quantized before being sent, as in Precision Guidance.

## F. COARSE GUIDANCE PROGRAM IMPLEMENTATION

### 1. Main Program and Subroutines

The Coarse Guidance simulation program consists of a main routine and two primary subroutines. The subroutine ARCRFT used to simulate true aircraft motion, was simplified from that version used in Precision Guidance in that all dive bombing equations were removed. The RADAR6 subroutine differs from RADAR9 by the obvious fact that it does not estimate acceleration due to bank angle bias, as well as in two other ways. The first is that RADAR6 is designed to operate at a sampling interval greater than the control interval. This requires that the subroutine be called, standard prediction equations executed, and then estimation only if the sampling interval has elapsed. The second difference is in the use of NWLD. NWLD indicates that "wild points" are in effect, and are ignored by the radar filter. This amounts to simple prediction without the benefit of radar sampled data.

The Coarse Guidance radar receives little if any return from the aircraft during command turns. In an effort to simulate this effect, NWLD is set to a negative value during turns, thus requiring prediction of position and velocity based only on past data and commands.

Coarse Guidance requires a little less than 100 K of core for linkage and execution. Compilation of the program

and subroutines requires about 25 seconds, and execution requires between 5 and 25 seconds, depending on the number of legs and the leg lengths.

A listing of the variables used in the program along with the variable definitions is provided at the end of Appendix A.

2. <u>Program Input and Output</u>

Specific format definitions for program input data are provided in Appendix C.

The program output consists of three primary parts. The first part is a listing of all input data and simulation run parameters. The second part is a summary of critical parameters printed once per second, and the third part is a summary of the deviation error from the desired path, along with a plot showing the desired, true and estimated paths.

At the beginning of each new leg, a summary of data table information is provided about that leg which can then be compared to what actually occurs. As the run progresses, a notification of the three stages of command turning is presented interspersed with the critical parameter summary.

The only performance criteria selected is the root mean square aircraft deviation from the desired path. The plot of the paths shows the deviations very well. The plot scaling is accomplished to maintain the same scale on both axes for a truer visual indication of relative error. All output values are in nautical miles and feet per second, for position and velocity, respectively.

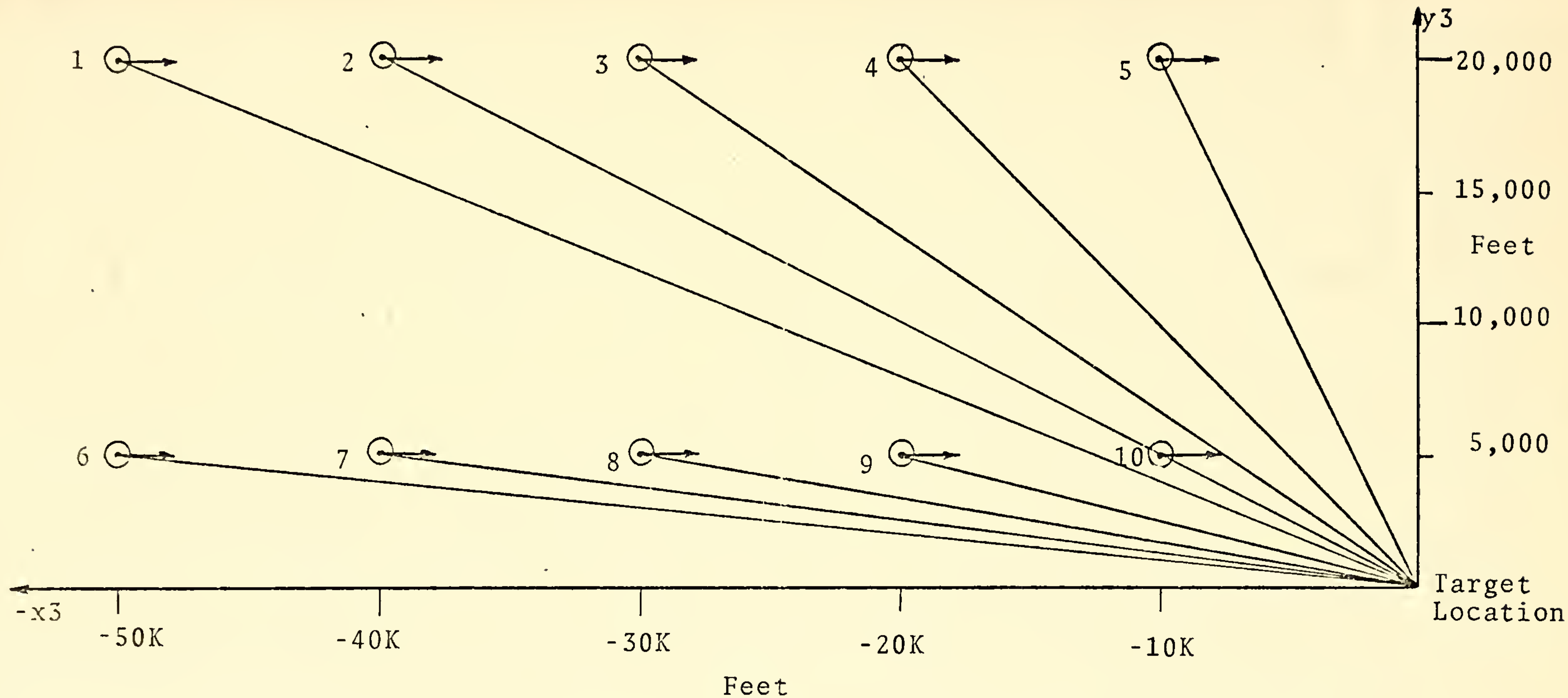
# V. PRESENTATION OF RESULTS

## A. PRECISION GUIDANCE PERFORMANCE COMPARISON

In the process of improving, changing, and verifying performance of the new version of the Precision Guidance simulation program, a very large number of runs were accomplished. A proper comparison between the two program versions requires side-by-side contrast of appropriate performance parameters, each derived from the same set of initial conditions.

In establishing specific run parameters for the initial conditions, three parameter sets were varied: initial aircraft position, X3, autopilot bias angle, $\phi_b$, and aircraft roll response time constant, $\tau_b$. All other variables in the programs were held constant and equal in the two program versions. Variation of the above parameters seemed to yield conditions which would ably show those areas where performance was improved, and at the same time permit runs with initial conditions varying from nearly perfect to considerably in error from the optimal initial bombing path.

Ten different aircraft initial positions were chosen and assigned a "run number." The initial velocity on each of these was identical. The resultant geometry created is shown in Fig. 18. Note that runs 1 through 5 present a considerably more difficult mission than runs 6 through 10. "Difficulty" can be roughly equated to the angle through which the aircraft must change its velocity in order to fly toward the target, located at the origin of the X3 coordinate system.




Initial velocities in each case were the same at 500 ft/sec in the x direction. Note that runs 1 through 5 represent rather extreme initial conditions, and that runs 6 through 10 are more realistic.

Figure 18. Illustration of Initial Position and Velocity Relationships for Runs Included as Results.

### 1. Filter Performance Comparison

The filters were tested within the framework of the Precision Guidance program. The most important performance parameter to monitor for this problem is the difference between the estimated position of the aircraft and the true position of the aircraft, already defined as the "residual" in II and III. Table I presents a comparison between the Kalman filter and the alpha-beta filter's radial residual, i.e., total estimation error in position, and Fig. 19 presents these results graphically. The numbers shown are average radial residuals, averaged over the runs accomplished for each version.

AVERAGE RADIAL RESIDUAL (ft)

| Run No. | Initial x3 | Original Version | Improved Version |
| --- | --- | --- | --- |
| 1. | -50,000 | 79 | 15 |
| 2. | -40,000 | 107 | 17 |
| 3. | -30,000 | 154 | 20 |
| 4. | -20,000 | 216 | 21 |
| 5. | -10,000 | 128 | 27 |

Table I. Comparison of Average Radial Residuals for the Alpha-Beta and Kalman Filters.

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The figures show an average percent improvement for the new program version of 680 percent, with a maximum improvement of over 1000 percent. It should be noted at this point that these numbers do not represent the results of a

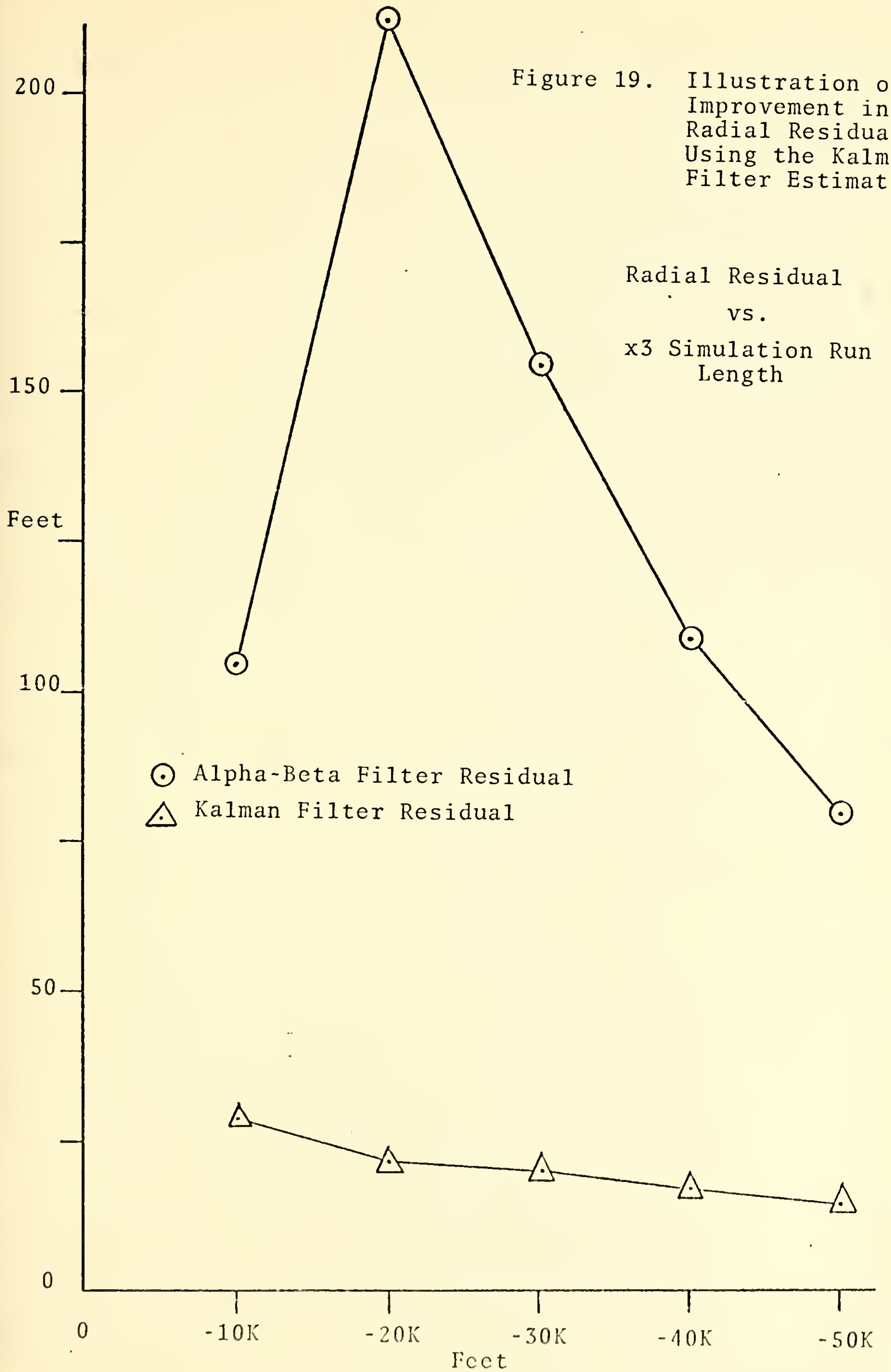



Figure 19. Illustration of Improvement in Radial Residual Using the Kalman Filter Estimator.

true Monte Carlo simulation. To achieve Monte Carlo precision would have required an inordinate amount of computer time to prove or illustrate a point. The differences in accuracy presented in TableIare not simply a result of stochastic luck on obtaining a "good" set of random numbers. The differences in the two versions represents a biasing in the original filter due to the lack of deterministic forcing. This point is brought out even more forcfully in the comparison of Figs. 20 and 21, and Figs. 22 and 23. These plots show that the errors in estimation for the Kalman filter on a typical run are roughly unbiased; however, the biasing on the estimation in both x and y coordinates from the alpha-beta filter is very obvious. Note that, as explained in II, the alpha-beta filter eventually "catches up" to the correct position. This occurs only after the initial period of banking at the limit is complete, and explains the peak in residual error which can be noted on the runs beginning at -20 K ft.

In theory, even if the alpha-beta filter had effects of deterministic forcing included, the Kalman filter would perform in a superior manner, due to its having an "optimal" gain schedule to give a minimum state covariance of error.

2. Bombing Accuracy and Time Response Comparison

Two performance parameters on the overall Precision Guidance routine were observed and minimized throughout program development. The importance of actual bombing accuracy is obvious. A less obvious but very important parameter

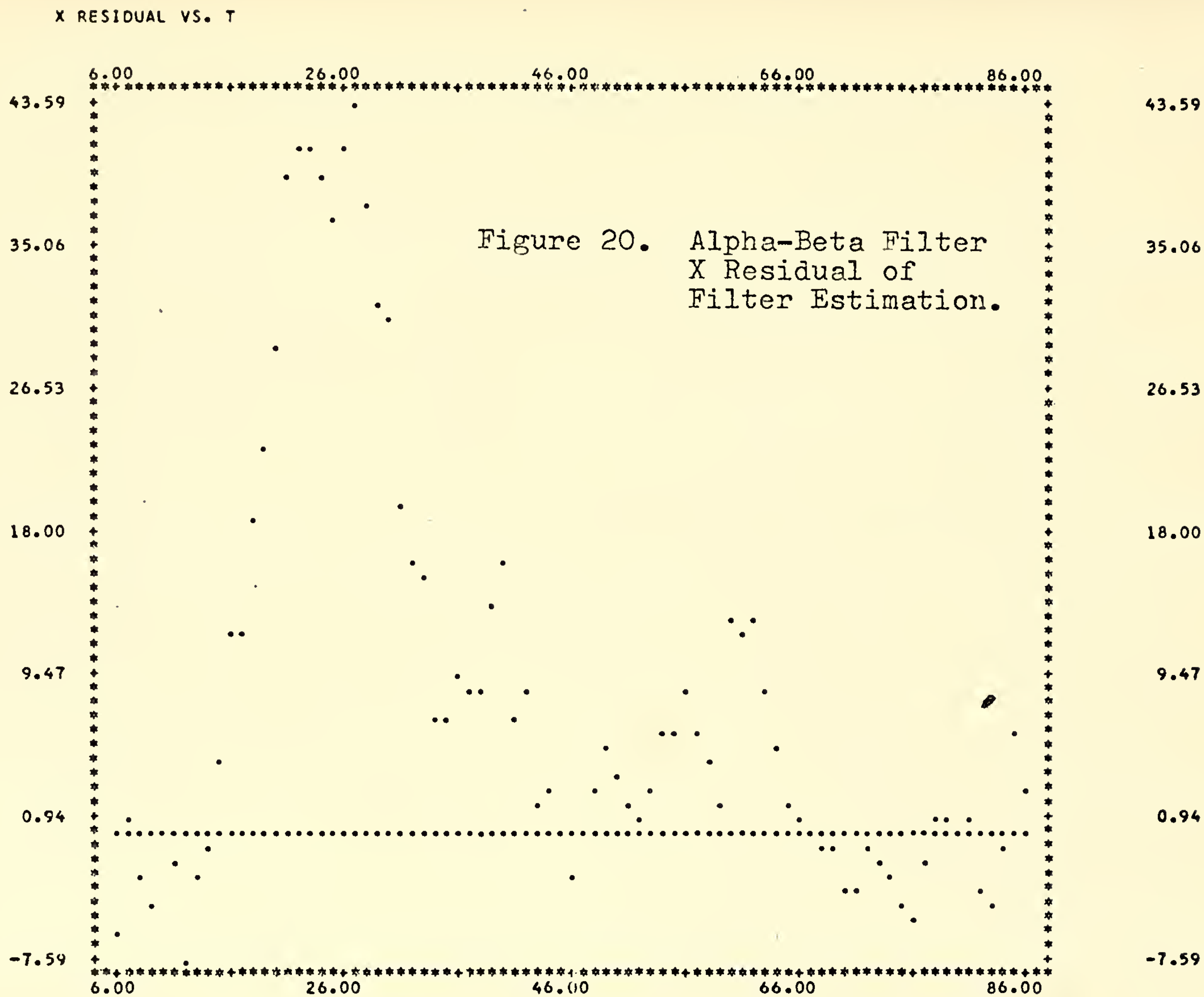



Figure 20. Alpha-Beta Filter X Residual of Filter Estimation.

X RESIDUAL VS. T

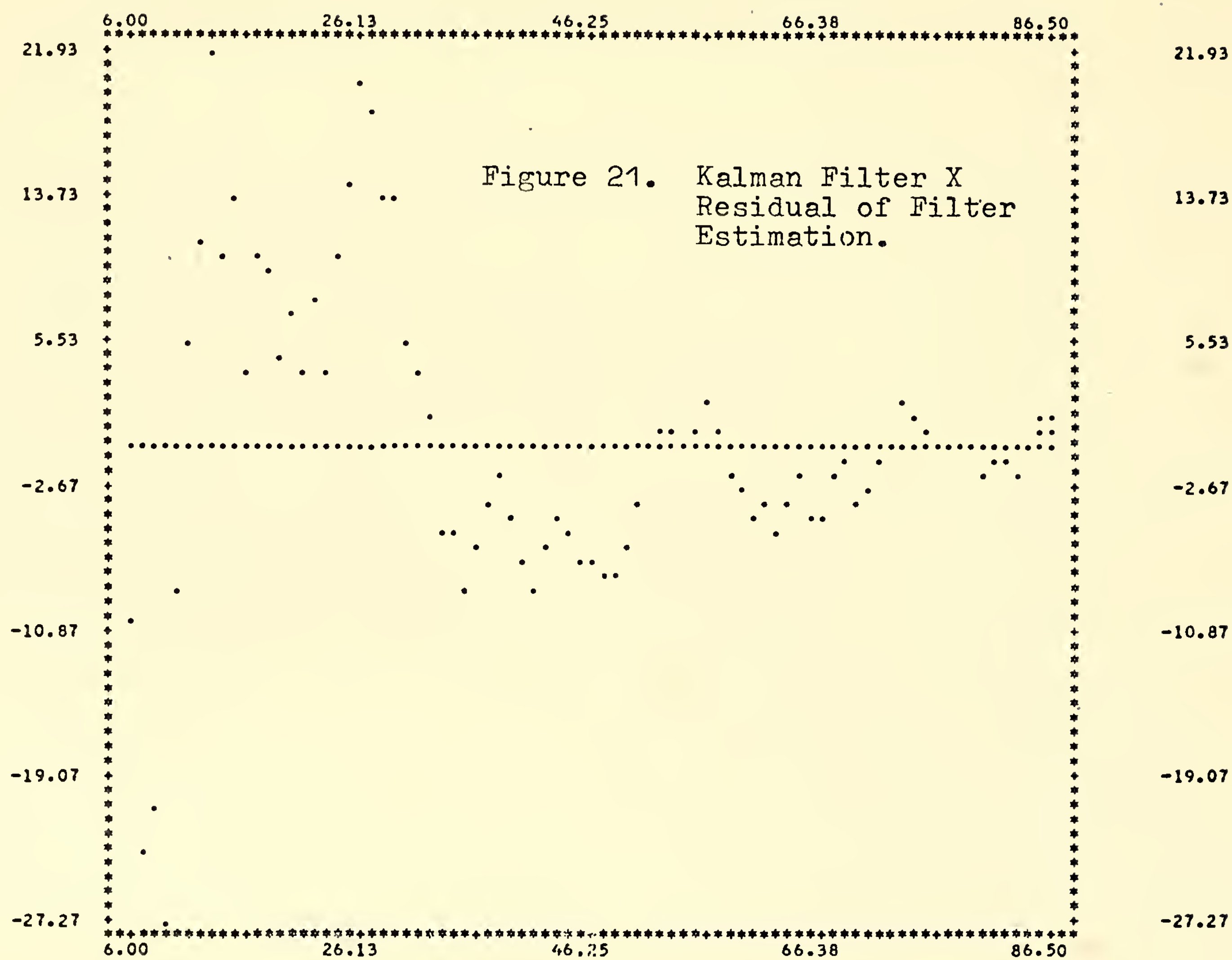



Figure 21. Kalman Filter X Residual of Filter Estimation.

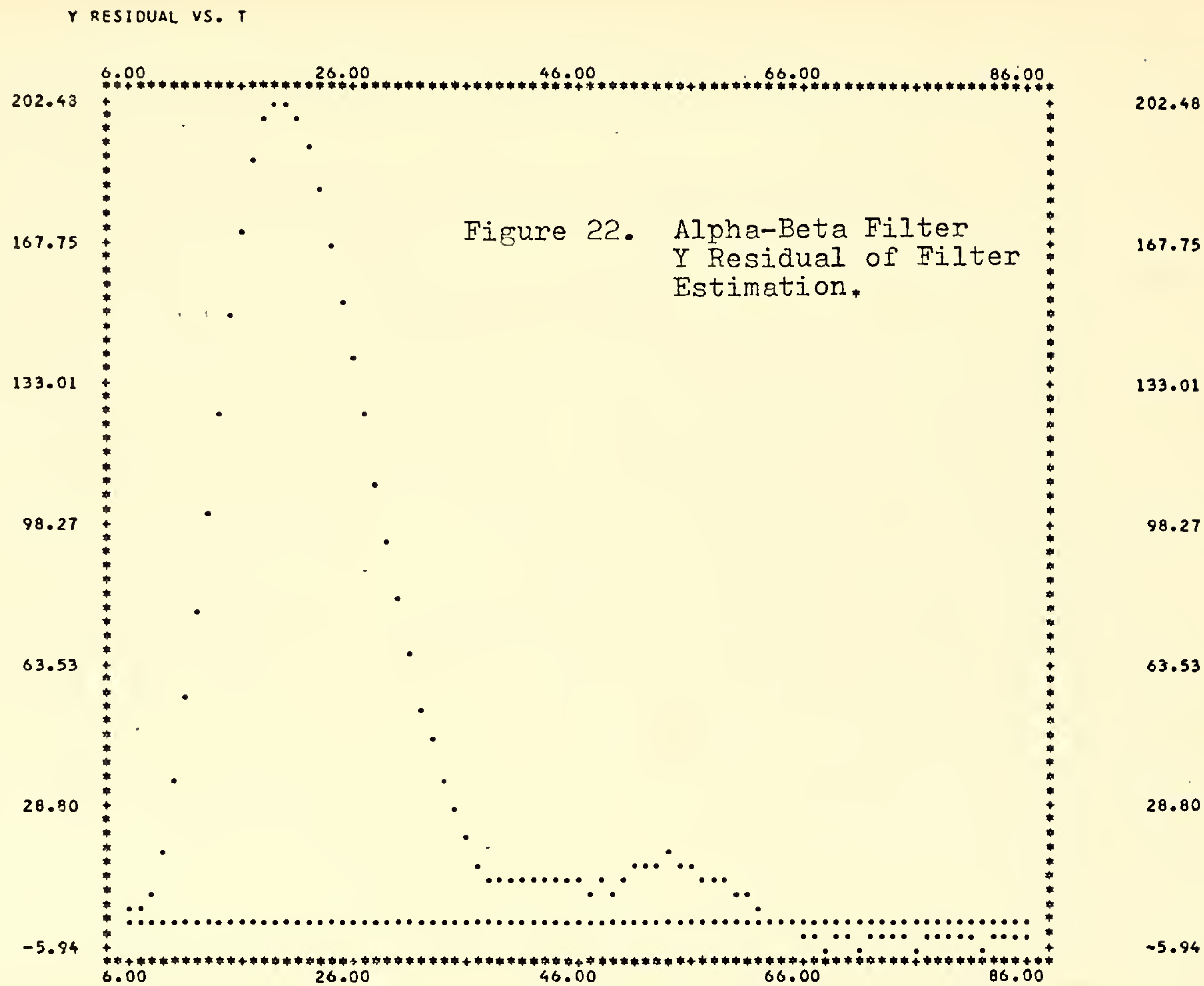



Figure 22. Alpha-Beta Filter
Y Residual of Filter
Estimation.

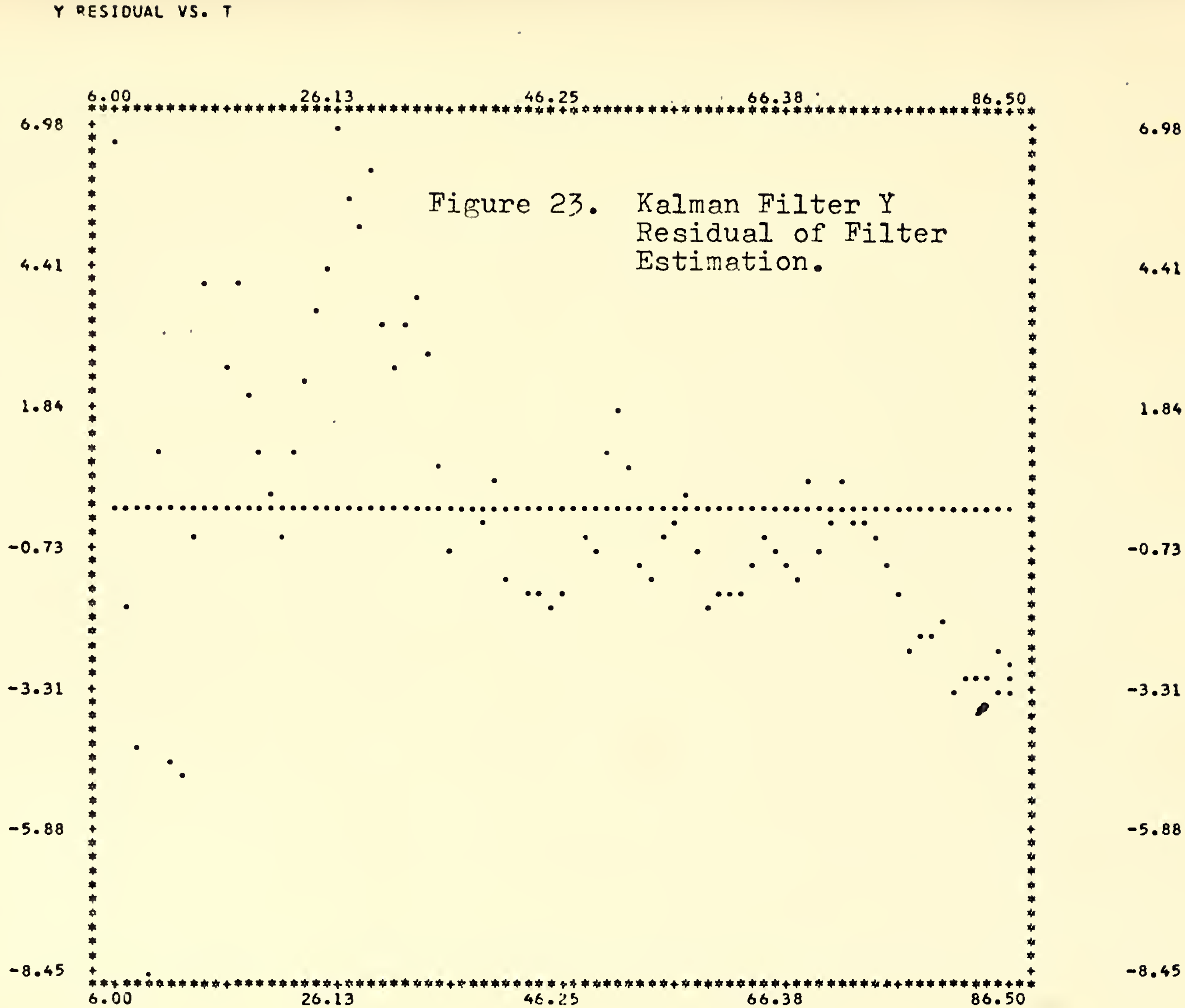



Figure 23. Kalman Filter Y Residual of Filter Estimation.

is the time required on the final bombing leg in order to achieve "sufficient" accuracy. The longer that a pilot is required to fly a straight path toward a target, the more his chances of being shot down increase. It is then desirable to swing onto the final leg from Coarse Guidance and complete the mission as soon as possible.

This time, to be designated T, was difficult to measure directly. It is a strong function of the amount of heading angle change required from Precision Guidance initialization. By varying the angles and distances to the target in the runs (1 through 10), it is possible to observe the amount of time required for the lateral error to reach some threshold minimum acceptable value, under which, in an absolute value sense, the bomb impact will be scored a successful mission. For the purpose of this study, this value was arbitrarily set at 70 feet.

Table II presents a summary of data from the simulation runs illustrating bombing accuracy and the time response parameter T. Note that most of the lists of bombing accuracies have a letter designation at the top of the respective columns. There are referenced on Figures 24 and 25, where comparisons of the bombing accuracies are presented graphically.

The inaccuracies resulting from those runs which start relatively close to the target are due to the fact that the aircraft cannot turn at a high enough rate to get on a bombing line passing near the target before it must drop the bomb. A

| Run No. Initial x3 | ORIGINAL VERSION | | | | IMPROVED VERSION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\tau_b=2$ | | | | $\tau_b=2$ | | | | $\tau_b=3.3$ | |
| | $\phi_b=0°$ | | $\phi_b=3°$ | | $\phi_b=0°$ | | $\phi_b=3°$ | | $\phi_b=3°$ | |
| | T | RI | T | RI | T | RI | T | RI | T | RI |
| y3 = 20,000 ft | | A | | B | | C | | D | | |
| 1. -50,000 | -- | 86 | -- | 90 | 22.5 | 12 | 19.5 | 28 | 23.5 | 32 |
| 2. -40,000 | -- | 151 | -- | 270 | 26.5 | 8 | 22.5 | 46 | 27 | 55 |
| 3. -30,000 | -- | 212 | -- | 331 | 32.5 | 9 | -- | 126 | -- | 145 |
| 4. -20,000 | -- | 3457 | -- | 1283 | -- | 2208 | -- | 199 | -- | 788 |
| 5. -10,000 | -- | 20130 | -- | 20104 | -- | 20394 | -- | 20147 | -- | 20147 |
| y3 = 5,000 ft | | E | | | | F | | | | |
| 6. -50,000 | 68 | 41 | | | 13.5 | 9 | | | | |
| 7. -40,000 | -- | 92 | | | 13.5 | 8 | | | | |
| 8. -30,000 | -- | 98 | | | 14.5 | 30 | | | | |
| 9. -20,000 | -- | 1120 | | | 19 | 29 | | | | |
| 10. -10,000 | -- | 20435 | | | -- | 6398 | | | | |

Table II. Precision Guidance Simulation Results. RI is bomb impact miss distance. T is time into run at which the lateral error dropped below 70 ft.

Figure 24. Illustration of Improvement in Bomb Impact Miss Distance for Varying Run Lengths. Initial y3 = 20,000 ft.
Original Program Results: Curves A,B
Improved Program Results: Curves C,D

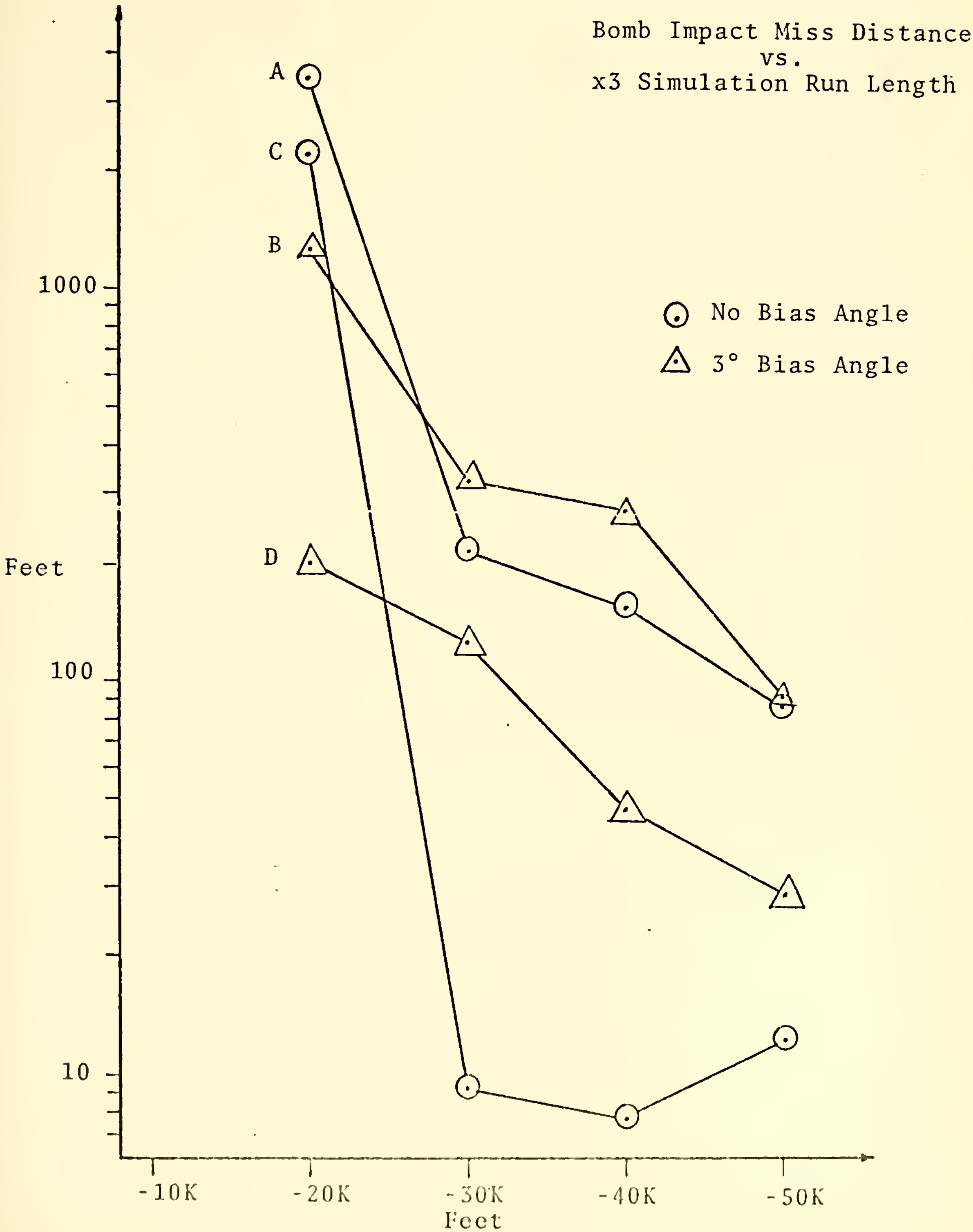
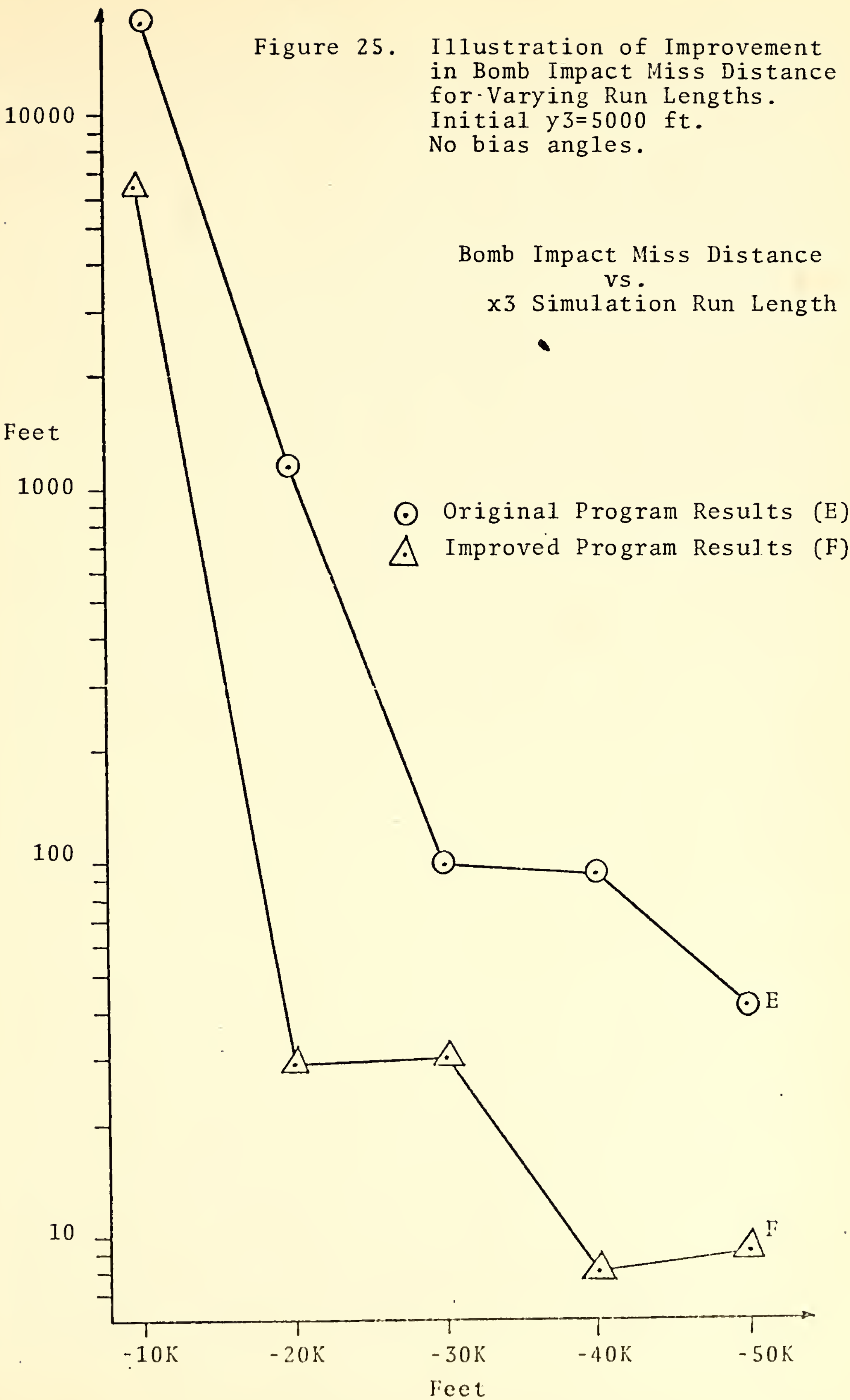
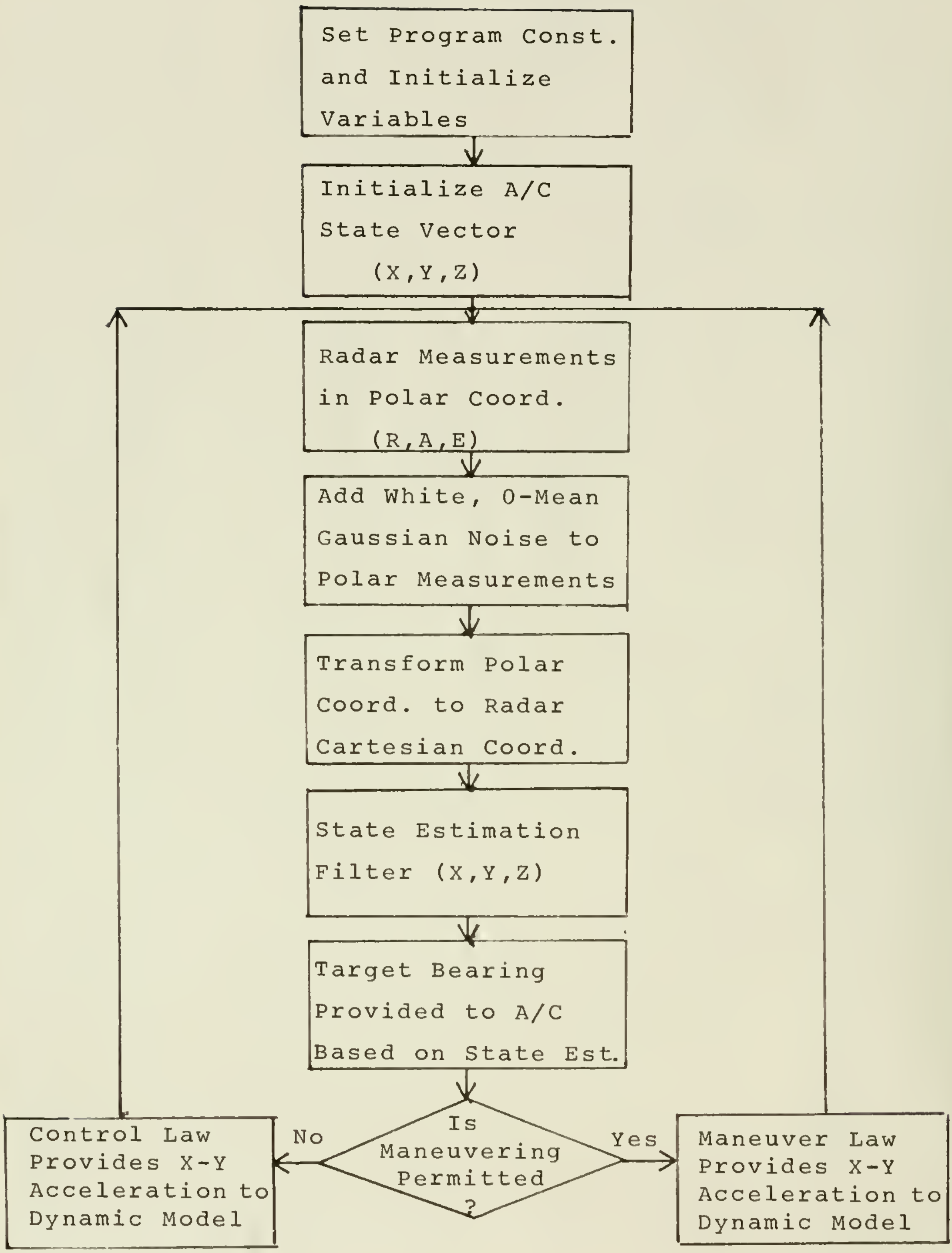


Figure 25. Illustration of Improvement in Bomb Impact Miss Distance for Varying Run Lengths. Initial y3=5000 ft. No bias angles.




Set Program Const. and Initialize Variables
Initialize A/C State Vector (X,Y,Z)
Radar Measurements in Polar Coord. (R,A,E)
Add White, 0-Mean Gaussian Noise to Polar Measurements
Transform Polar Coord. to Radar Cartesian Coord.
State Estimation Filter (X,Y,Z)
Target Bearing Provided to A/C Based on State Est.
Is Maneuvering Permitted ?
No
Yes
Control Law Provides X-Y Acceleration to Dynamic Model
Maneuver Law Provides X-Y Acceleration to Dynamic Model

large part of the error improvement which can be seen in these two figures is due to the filter improvement. However, the controller also has a large effect on the overall response of the aircraft. The use of angle rate feedback helps to drive the lateral error to zero faster than in the original version. This is presented graphically in Fig. 26. Note also that while the original version suffers the effect of a large overshoot past zero lateral error, the improved version does not. This is fundamentally the result of the rate feedback acting as a damper.

Examination of T in Table II whill show that the original simulation program achieved a lateral error below 70 feet only once in the simulation trials run. The improved version reached the acceptable error 9 out of 15 times. Inspection of the times will show that very little time is required to achieve this figure of accuracy, including those runs which are initialized with rather extreme initial error angles (e.g., 3, 8, and 9). Use of the new algorithms to estimate position and control the aircraft should result in a marked improvement in overall accuracy in bombing and in time on the final leg required to achieve this accuracy.

## B. COARSE GUIDANCE PERFORMANCE

No contrasting performance tests were performed for the Coarse Guidance mode. The primary reason for this is the lack of sufficient program documentation on the original version of Coarse Guidance. Thus, the Coarse Guidance results

LATERAL ERROR (XE) COMPARISON PLOT

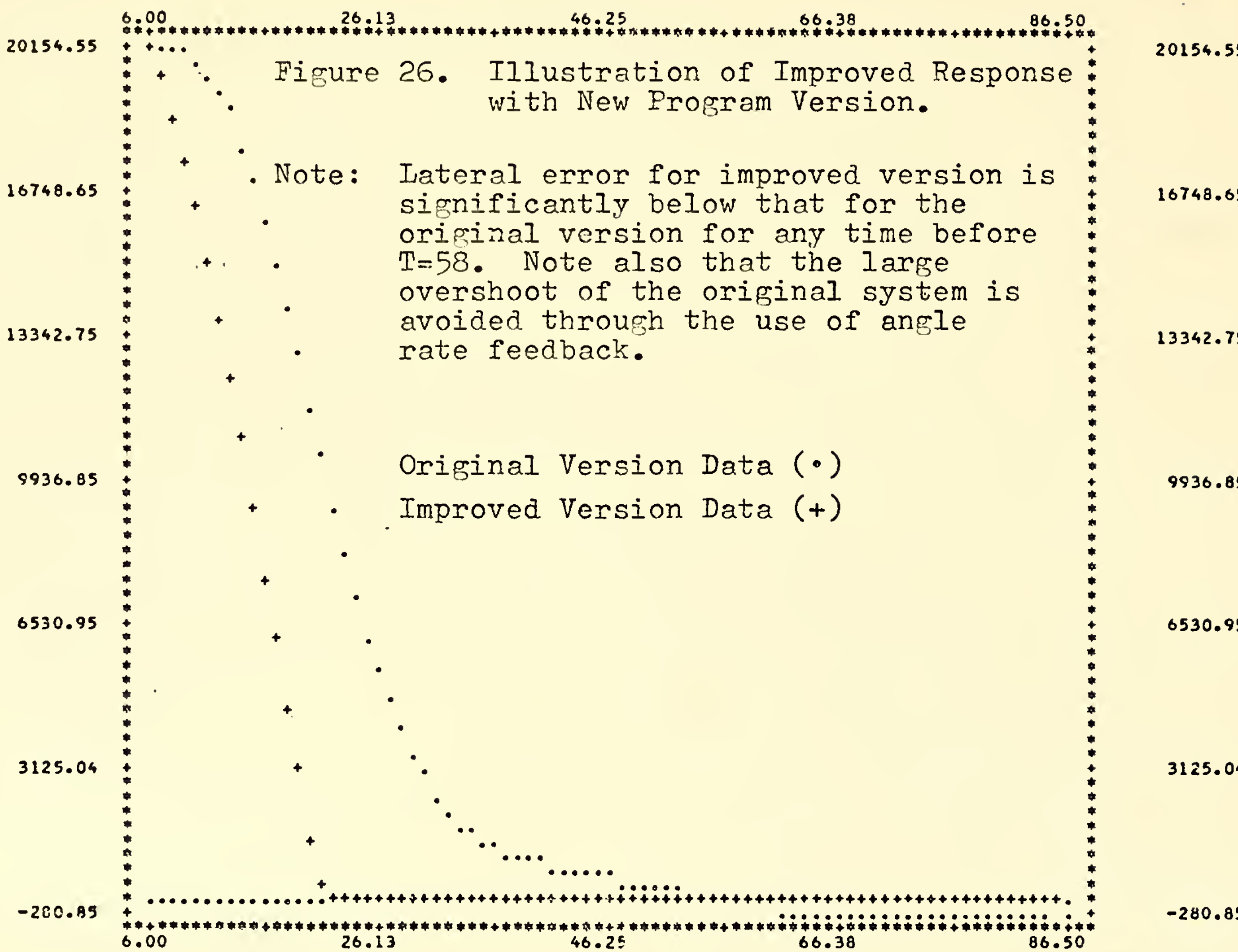



Figure 26. Illustration of Improved Response with New Program Version.

Note: Lateral error for improved version is significantly below that for the original version for any time before T=58. Note also that the large overshoot of the original system is avoided through the use of angle rate feedback.

presented must stand on their own merit, on an absolute instead of a relative performance scale.

As was the case for Precision Guidance, a large number of Coarse Guidance simulation runs were completed in the process of obtaining the final program version. A sample of some of the representative track plots with the RMS track deviations for those runs are presented in Figs. 27 through 30. The significant aspects of each of these runs are discussed below.

Figure 27 represents a rather simple track to follow, and is probably the most realistic track of the four presented. The turns to be executed and the initial heading and position errors are not excessive. The control and turn logic caused the aircraft to follow the desired path very closely.

The scale on Fig. 28 is about half of that for Fig. 27 and thus the initial errors are more obvious. The track deviation figure is higher here than before due to the fact that the initial errors tend to take the aircraft away from the desired track, vice in the track's general direction, as was the case for Fig. 27. Note that the control logic has caused the aircraft to fly toward the second waypoint. At the appropriate time, the aircraft begins a command turn in order to be aligned properly on the second leg upon turn completion. The error from this point on is minimal, never exceeding 0.28 NM on the final leg.

Figure 29 illustrates a most unlikely track to be encountered in practice, but one which checks out the program

DESIRED, TRUE, AND ESTIMATED POSITION

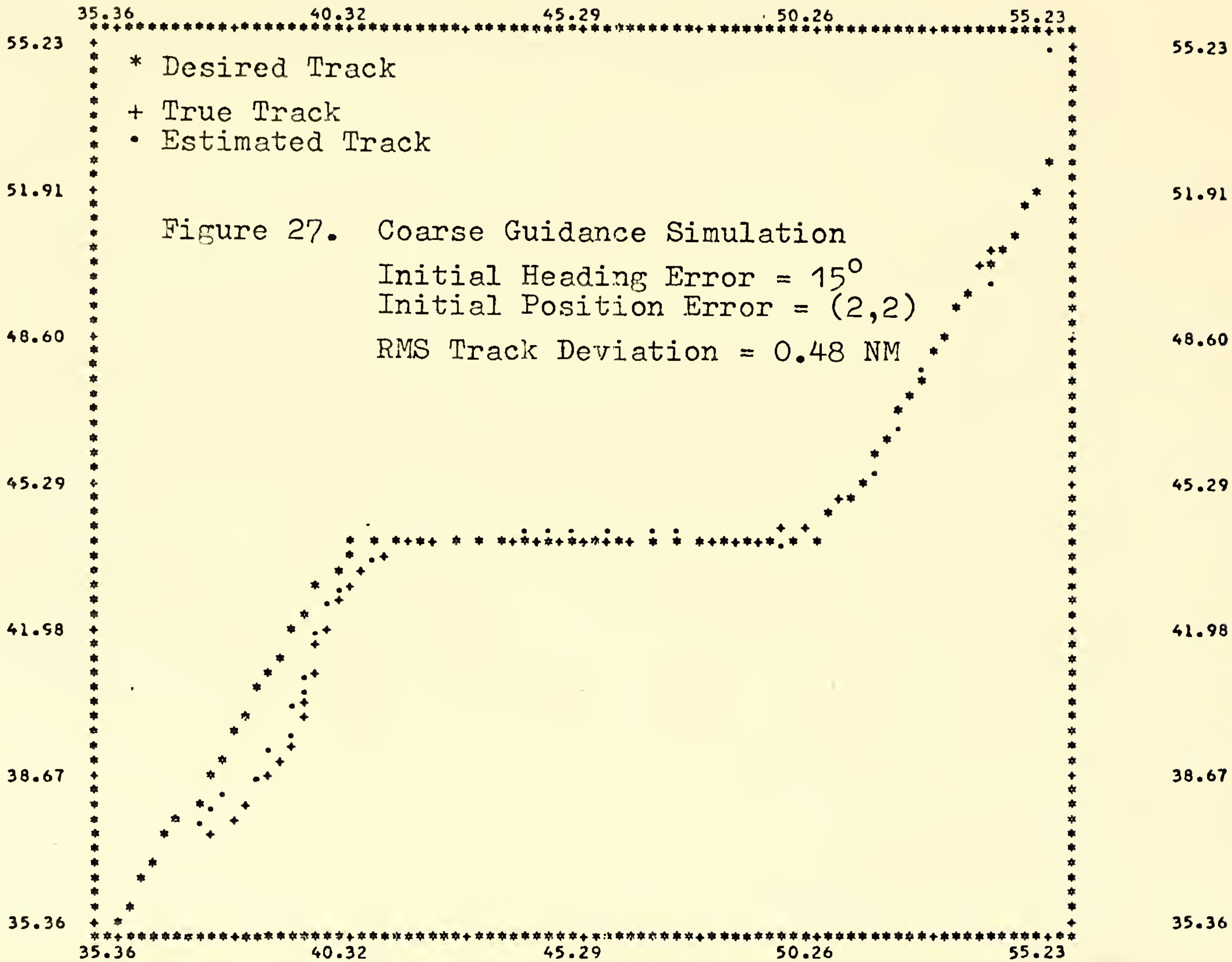



Figure 27. Coarse Guidance Simulation

Initial Heading Error = 15°
Initial Position Error = (2,2)

RMS Track Deviation = 0.48 NM

DESIRED,TRUE, AND ESTIMATED POSITION

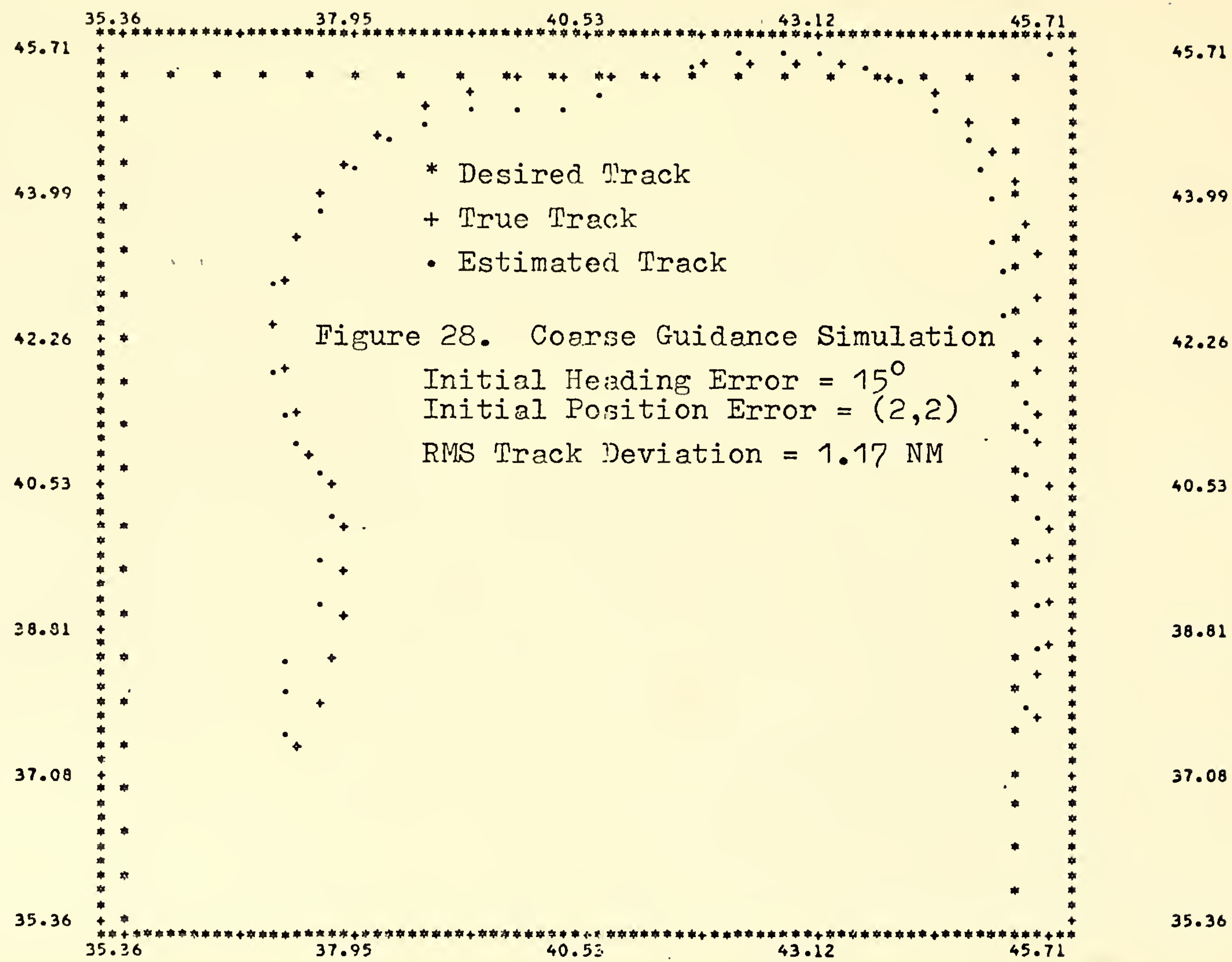



Figure 28. Coarse Guidance Simulation

Initial Heading Error = 15°
Initial Position Error = (2,2)

RMS Track Deviation = 1.17 NM

DESIRED,TRUE, AND ESTIMATED POSITION

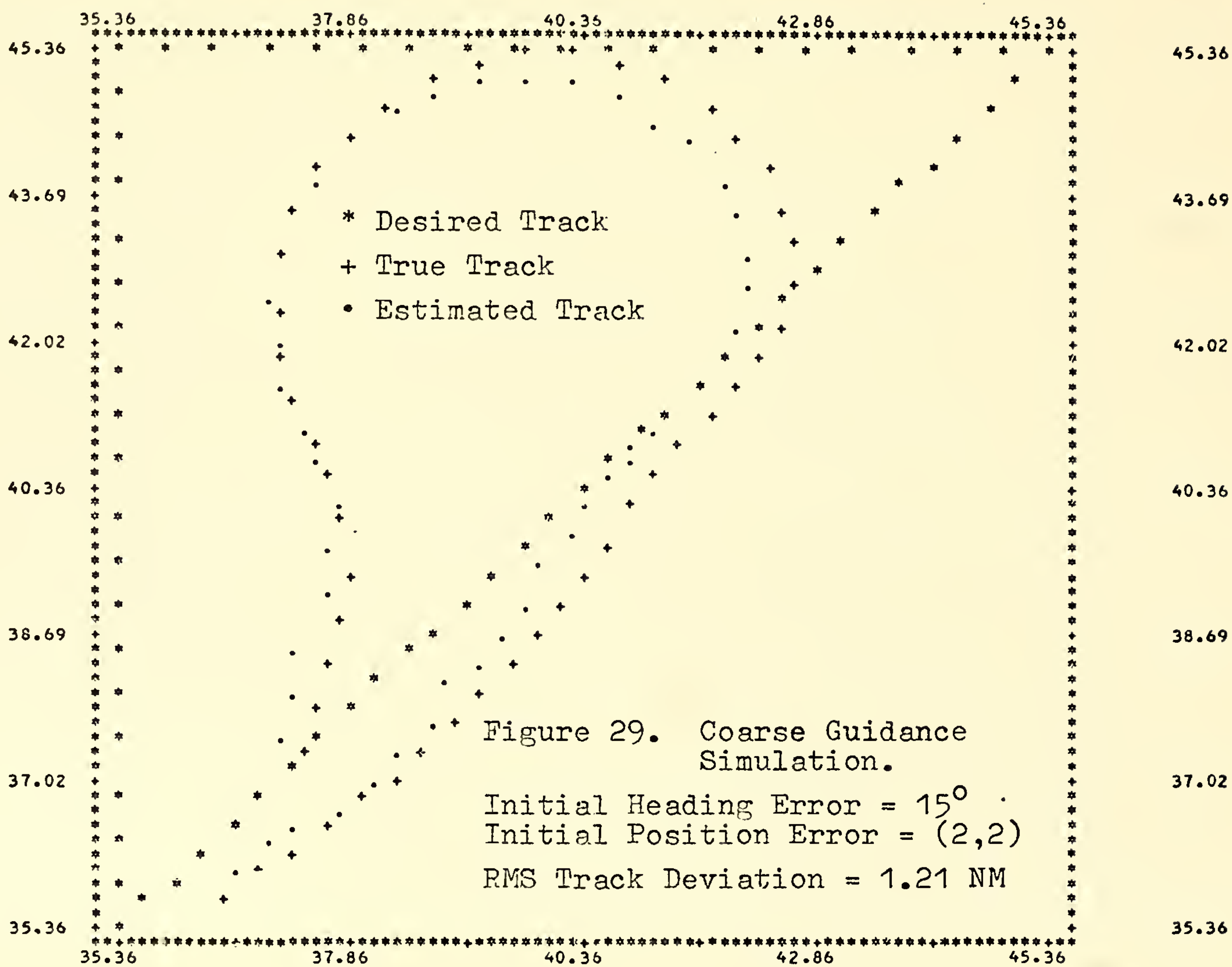



Figure 29. Coarse Guidance Simulation.

Initial Heading Error = $15^{\circ}$
Initial Position Error = (2,2)

RMS Track Deviation = 1.21 NM

algorithms quite well. The initial errors are as before. In this case, the aircraft exists from the first command turn only to note through turning logic that it is already a few seconds behind schedule to be able to make the correct turn onto the final leg. This is because of the combined condition of a relatively short leg length remaining and a requirement to execute 135° change in heading. It can be seen from the plot that the aircraft was not able to come to the correct final leg heading of 225° from the command turn control alone. Another effect which is evident from this run is the lack of position update information in the filter during a command turn, due to poor radar return simulation.

Figure 30 is the result of a track of the same shape as that used in Fig. 29, except the legs are twice as long. The initial position error is also the same as that for Fig. 29, but the initial heading error from the desired track in this case is 90°. The purpose of this track is to show that the program's algorithm can handle effectively a case such as that in Fig. 29, provided the given physical constraints of the system permit time to react.

Note that the aircraft performs the correct course change and heads for the second waypoint, and from that point on is nearly coincident with the desired track. The relatively high track deviation figure for this run is due almost entirely to the effects of the initial heading and position errors.

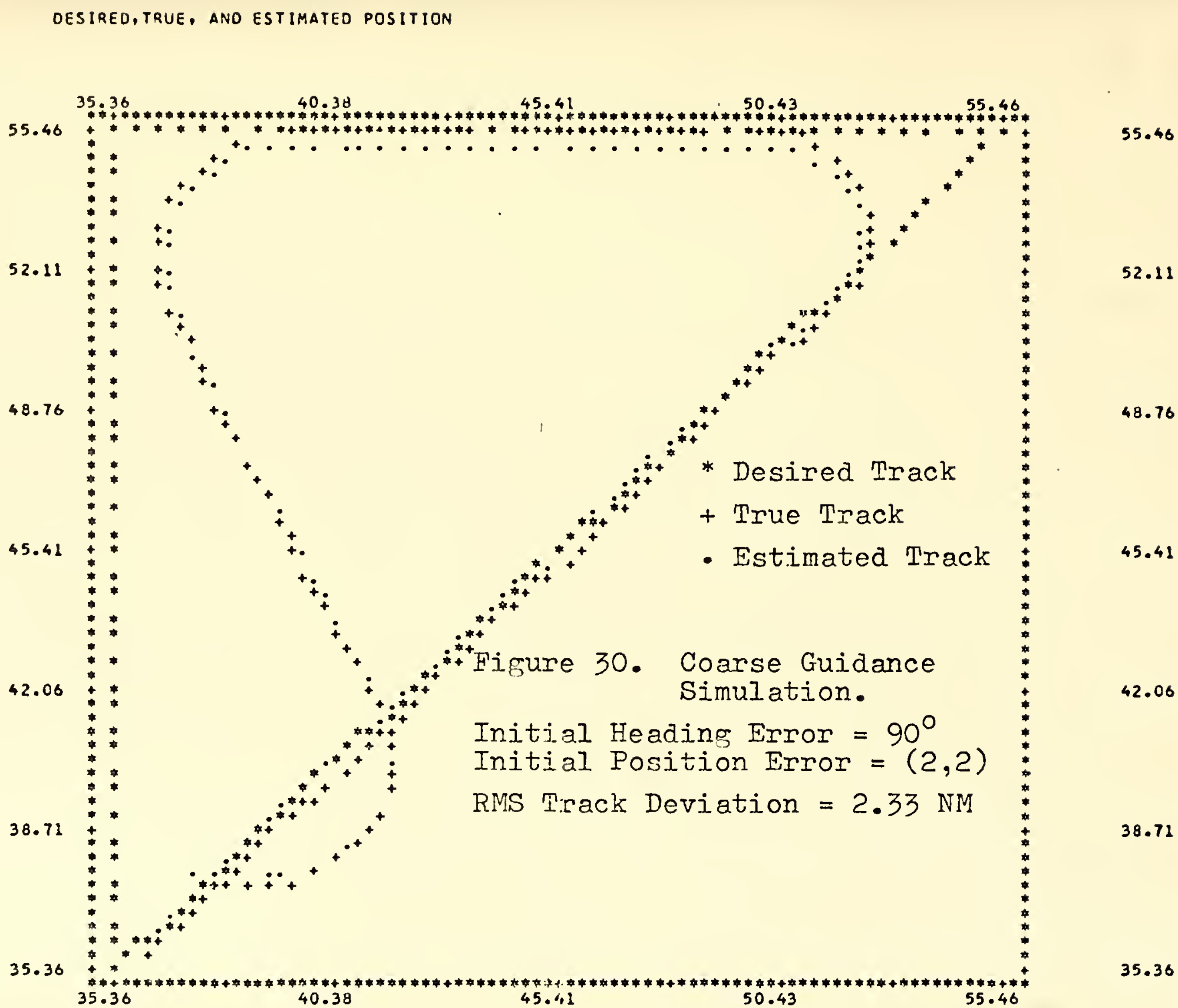



Figure 30. Coarse Guidance Simulation.

Each of these runs was made with a minimum error heading for correction, $H_{ermin}$, of 5°. Use of this number on runs for which excessive initial errors were not present, i.e., Figs. 27 and 28, resulted in a command correction being sent less than 10 percent of the time during which command turns and initial error corrections were not in progress. This indicates a vast improvement towards the goal of decreasing the numbers of mid-course corrections being sent to the pilot during this phase of the problem.

Autopilot control of the aircraft during this phase was assumed because it was not known how to realistically model the effects of a pilot receiving an instruction to come to a new heading. If pilot control of the aircraft is desired, the algorithms used provide a heading error which could be used. In fact, it is this value which is used to compute the bank angle correction.

In summary, the improved Coarse Guidance algorithms appear to yield a greatly simplified and accurate technique for guiding the aircraft onto the final leg. In addition, the errors in position and heading as the aircraft enters the final leg are such that the Precision Guidance filter can be initialized with valid nonzero velocities, and thus the time required on the final leg can be reduced even further, since the requirement for a full six seconds without control could be reduced.

## APPENDIX A: LIST OF PRINCIPLE VARIABLES FOR THE PRECISION AND COARSE GUIDANCE SIMULATION PROGRAMS

### A. PRECISION GUIDANCE MAIN ROUTINE

| | |
|---|---|
| ATITLE-ZTITLE | Titles of the plots |
| BIS | Means of RADAR9 R, θ, and ϕ noise |
| BFF | Bomb ballistics form factor |
| D | Bomb diameter |
| DEG | Radian/degree conversion factor |
| DT | Radar sampling interval |
| DTCON | Control update interval |
| EM1 | Matrix to convert from target to radar reference frame |
| EM2 | Matrix to convert from radar to target frame |
| EM3 | Matrix to rotate from X5 to X6 reference frame |
| EV1 | Translation matrix to go from target to radar reference frame |
| FILRES | Contains estimation error in radar frame for x,y,z, and radial |
| G | Gravitational constant, 32.2 ft/sec$^2$ |
| HDE | Heading error angle |
| HDEDOT | Time derivative of HDE |
| HA | Height of target above sea level |
| IB1 | Equal to 0 in level bombing mode |
| IDTCON | Integer relating DT to DTCON |
| ITAB1 | Counter for number of points to plot |
| ITH | Equal to the number of times through main processing loop, except on last time through, when equal to -1 |
| IU | Seed for random number generator, NORMAL |
| KTH | Counter to indicate time for integration for RA and TF calculations |
| MWLD | Number of "wild points" to be thrown out by RADAR9 as invalid |

| | |
|---|---|
| NWLD | Set equal to MWLD at time TWLD and decremented as "wild points" are used |
| NTB | Number of bombing constant table to be used |
| PH | True bank angle |
| PH1 | Estimated bank angle |
| PHD | Desired feedback command |
| PHD1 | Desired feedback command from HDE |
| PHD2 | Desired feedback command from HDEDOT |
| PHDAVG | Command to be ordered for last two seconds before bomb release |
| PHB | Autopilot bias bank angle |
| PHC | Command bank angle sent |
| PS | True aircraft heading angle in target frame |
| PS1 | Estimated aircraft heading angle in radar frame |
| PSD | True aircraft turning rate |
| RE | Radius of the Earth |
| RBT | Distance from aircraft (estimated) to the target |
| SIG(1) - SIG(3) | Standard deviations of R, $\theta$, and $\phi$ |
| SIG(4) - SIG(6) | Initial radar velocity estimates |
| SIGW | Standard deviations of random forcing to be assumed for calculation of Q |
| T | Time into the simulation run |
| TB | $\tau_b$, the aircraft roll response time constant |
| TG | Time-to-Go to release bomb |
| TF | Time of fall for the bomb |
| TLVL | Time for required level flight before bomb release; equal to two seconds |
| TLVL1 | Equal to TLVL +1 |
| VE | Total airspeed |
| VEH | Horizontal airspeed |
| W | Weight of bomb in pounds |
| WH | Estimated wind in target frame |
| WR | Estimated wind in radar frame |
| WT | True wind in target frame |

| | |
|---|---|
| X1,XD1,XDD1 | Estimated position, velocity and acceleration in radar frame |
| X2,XD2 | True position and velocity in radar frame |
| X3,XD3 | True position and velocity in target frame |
| X5,XD5 | Estimated position and relative velocity of target with respect to the aircraft; "primed system" |
| X6,XD6 | X5,XD5 system rotated to align the YD6 axis pointing at the target; for printing and plotting purposes, this vector contains the error between true and estimated position in the X3/X5 frame |
| XE | Lateral error |
| XGC | X bomb impact point in X6 frame |
| XXA-XXG | Arrays used to store variables for plotting at program end |
| YYA-YYU | Arrays used to store variables for plotting at program end |
| YGC | Y bomb impact point in the X6 frame |

B. SUBROUTINE ARCRFT

| | |
|---|---|
| CA1 - CA5 | Constants used in aircraft motion equations |
| DT | Radar sampling interval; also interval of update for aircraft true position |
| DEG | Radian/degree conversion factor |
| DT3 | Equal to DT/2 |
| G | Gravitational acceleration, 32 ft/sec$^2$ |
| ITH | Equal to number times through loop, except on last time when ITH = -1 |
| IB1 | Equal to zero for level flight mode |
| PH | True bank angle |
| PHB | Bank angle bias |
| PHC | Command bank angle |
| PHN | New bank angle |
| PS | Heading angle |
| PSD | Heading angle rate |
| PSDN | New heading angle rate |

| | |
|---|---|
| PSN | New heading angle |
| T | Elapsed time since start of run |
| TB | $\tau_b$, the roll response time constant |
| TG | Time to go to release bomb |
| VT | Horizontal airspeed |
| WT | True wind vector |
| X3 | Aircraft position in target frame |
| XD3 | Aircraft velocity in target frame |

C. SUBROUTINES RADAR6 AND RADAR9

| | |
|---|---|
| A | Azimuth angle |
| ADDSUB | Subroutine entry to add or subtract two matrices |
| ADUM | Temporary array used in matrix arithmetic |
| ANGMAX | Maximum angle, used to prevent overflow |
| ANGMIN | Minimum angle, used to prevent underflow |
| BIS | Range, azimuth, and elevation noise bias |
| BDUM | Temporary array used for matrix arithmetic |
| CA1,CA4,CA5 CAA2 | Constants used in aircraft motion equations |
| DEG | Radian/degree conversion constant |
| DT | Radar sampling interval in RADAR9 |
| DTRAD | Radar sampling interval in RADAR6 |
| DTCUM | Accumulator to determine next time to sample position in RADAR6 |
| DT2 | Equal to $DT^2/2$ |
| DTRAD2 | Equal to $DTRAD^2/2$ |
| DT3 | Equal to DT/2 |
| DT4 | Equal to $DT^3/6$ |
| E | Elevation angle |
| E1,E2,E3 | Difference between predicted position and data sample during state estimation |
| G | Gain matrix |

| | |
|---|---|
| GG | Gravitational acceleration, 32 ft/sec$^2$ |
| GAMMA | $\Gamma$ matrix |
| GNX,GNY,GNZ | G(1,1), G(4,2), and G(7.3) terms of the gain matrix |
| H | Measurement matrix |
| HT | Measurement matrix transposed |
| INVERT | Subroutine entry to invert a matrix |
| ITH | Equal to number of times through main processing loop, except on last time through when ITH = -1 |
| IU | Seed for random number generator, NORMAL |
| NORMAL | Subroutine to generate normally distributed random variables to be used as noise |
| PE | Covariance of estimation error matrix |
| PH1 | Estimated bank angle |
| PHC | Command bank angle |
| PHI | State transition matrix used for gain generation only |
| PHITRN | Transpose of PHI |
| PROD | Subroutine entry to perform the product of two matrices |
| PS1 | Estimated heading angle with respect to the wind |
| PSN | Predicted new heading angle before acceleration estimate correction |
| PSD1 | Estimated turning rate |
| Q | Array resulting from expected random forcing assumption |
| R | Range to target |
| RAN | Contains random numbers from NORMAL |
| SIG(1) - SIG(3) | Standard deviation for R, $\theta$, and $\phi$ |
| SIG(4) - SIG(6) | Initial velocity estimates for prediction |
| SIGW | Standard deviations of random forcing in x,y, and z of radar frame |
| TB | Roll response time constant, $\tau_b$ |
| TRANS | Subroutine entry to perform the transpose of an array |

| | |
|---|---|
| VT1 | Estimate of horizontal airspeed |
| VARR,VART,VARP | Variances of R, θ, and ϕ |
| WR | Estimated wind vector in the radar frame |
| X1,XD1,XDD1 | Estimated state vector in radar frame (XDD1 not used in RADAR6) |
| X2,XD2 | True state position and velocity in the radar frame |
| X1P,XD1P,XDD1P | Predicted state vector in radar frame |
| XDATA | Cartesian radar observation with noise |
| XIDENT | Identity matrix |

D. COARSE GUIDANCE MAIN ROUTINE

| | |
|---|---|
| ATITLE-ETITLE | Titles for plots |
| AZ | Array for storing average leg azimuths |
| AZI | Initial azimuth for first leg |
| BIS | Array for RADAR6 noise biases |
| DEG | Degree to radian conversion factor |
| DEL | Initial displacement vector for true aircraft position |
| DT | Set equal to DTCON |
| DTCON | Control update interval |
| DTRAD | Radar sampling interval |
| DTG | Distance from X1 to leg intersection |
| EEST | Estimated aircraft deviation from leg |
| ETRUE | True aircraft deviation from leg |
| FEET | Feet-to-nautical mile conversion factor |
| G | Gravitational acceleration constant |
| G1 | HDE gain constant, $G_1$ |
| G2 | HDEDOT gain constant, $G_2$ |
| H | Array of desired air headings |
| HEA | Estimated aircraft air heading |
| HTA | True aircraft air heading |
| HEG | Estimated aircraft ground heading |

| | |
|---|---|
| HTG | True aircraft ground heading |
| HDE | Heading angle error |
| HDEDOT | Heading angle error rate |
| HERMIN | Minimum error angle for which commands will be sent |
| I | Equal to the index on the current leg |
| IDTRAD | Integer relating DTCON and DTRAD |
| IEND | Equal to 0 except on last leg |
| ITH | Equal to the number of times through the main processing loop |
| IU | Seed for the random number generator |
| NLEG | Number of legs for the run |
| PHB | Bias angle; assumed zero |
| PHC | Command bank angle |
| PHD | Desired bank angle from controller |
| PLENGTH | Length of each leg |
| RAD | Radian to degree conversion factor |
| RMSEST | RMS value of EEST |
| RMSETR | RMS value of ETRUE |
| RANGE | Array containing average range to each leg |
| RANGEI | Range to start of first leg from the radar |
| SIG(1) - SIG(3) | Standard deviations for R, θ, and ϕ |
| SIG(4) - SIG(6) | Initial velocities for filter prediction |
| SIGW | Standard deviations for assumed random forcing; assumed zero for all runs in this study |
| T | Time into simulation run |
| TB | True aircraft roll response time constant |
| TAUH | Estimated aircraft roll response time constant; set equal to TB for all runs in this study |
| TINTRN | Time into a command turn |
| THETA | Array containing azimuths of each leg |
| THETW | Direction toward which true wind blows |

| | |
|---|---|
| THETWH | Direction toward which estimated wind blows |
| TLEG | Array containing desired time to cover each leg |
| TLEG1 | Estimated time remaining on a leg |
| TSTOP | Time at which problem ends |
| TSTPTN | Time at which a zero bank command is sent to end a turn |
| TTOTTN | Time at which a turn is completely over |
| TG | Time to go to start a turn |
| VA | True airspeed |
| VAH | Estimated airspeed |
| VEG | Estimated ground speed |
| VTG | True ground speed |
| VW | True wind speed |
| VWH | Estimated wind speed |
| WR | Equal to WH; components of estimated wind |
| WT | Components of true wind |
| X1,XD1 | Estimated aircraft position and velocity |
| X2,XD2 | Desired track data; used for plotting only |
| X3,XD3 | True aircraft position and velocity |
| XWP | Array containing x waypoint co-ordinates |
| XXA-XXE | Arrays for use in plotting |
| YYA-YYE | Arrays for use in plotting |
| YWP | Array containing y waypoint co-ordinates |

Note: There are several variables with the suffix NM. These variables correspond to the variable without the suffix, except the NM indicates the value stored is in nautical miles.

## APPENDIX B: PRECISION GUIDANCE INPUT DATA FORMAT DEFINITION

| CARD | COLUMNS | FORMAT | VARIABLE | REMARKS |
|---|---|---|---|---|
| 1 | 1-10 | F10.3 | WT(1) | True wind in target frame |
| | 11-20 | | WT(2) | x,y, and z directions;WT(3) |
| | 21-30 | | WT(3) | is usually zero |
| | 31-40 | | WH(1) | Estimated wind in target |
| | 41-50 | | WH(2) | frame;WH(3) is usually |
| | 51-60 | | WH(3) | zero |
| 2 | 1-10 | | BIS(1) | Bias on range, azimuth |
| | 11-20 | | BIS(2) | and elevation noise |
| | 21-30 | | BIS(3) | |
| | 31-40 | | SIG(4) | Initial velocity estimates |
| | 41-50 | | SIG(5) | for filter prediction |
| | 51-60 | | SIG(6) | |
| 3 | 1-10 | | SIG(1) | Standard deviations on |
| | 11-20 | | SIG(2) | range, azimuth, and |
| | 21-30 | | SIG(3) | elevation noise |
| 4 | 1-10 | | SIGW(1) | Standard deviations of |
| | 11-20 | | SIGW(2) | assumed random forcing in |
| | 21-30 | | SIGW(3) | x,y,and z of radar frame |
| 5 | 1-10 | | X3(1) | Initial position (x,y,z) |
| | 11-20 | | X3(2) | of aircraft in target |
| | 21-30 | | X3(3) | frame |
| 7 | 1-10 | | PHB | Autopilot bias angle |
| | 11-20 | | TB | Roll response time constant |
| | 21-30 | | DT | Radar sampling interval |
| | 31-40 | | DTCON | Control update interval |
| | 41-50 | | PHI | Latitude of target |
| | 51-60 | F10.3 | TWLD | Time to start wild points |
| | 61-63 | I3 | MWLD | Number of wild points |

| CARD | COLUMNS | FORMAT | VARIABLE | REMARKS |
|---|---|---|---|---|
| 8 | 1-10 | F10.3 | T3 | Nominal dive duration |
| | 11-20 | | THNM | Combine to give angle |
| | 21-30 | | THDM | radar and target |
| | 31-40 | | THD | Nominal dive angle |
| | 41-50 | | ATT | True tang. accel. during dive |
| | 51-60 | | ATH | Est. tang. accel. during dive |
| 9 | 1-10 | | ANH | Max. aircraft normal accel. |
| | 11-20 | | TUP | Aircraft pitch time constant |
| | 21-30 | | HTOL | Angle and altitude tolerances |
| | 31-40 | | ATOL | for dive pullout |
| | 41-50 | F10.3 | S | Equal to 9999 |
| | 51-53 | I3 | IB1 | Equal to zero for level flight |
| | 54-56 | I3 | IACC | Equal to zero for no acceleration compensation |
| 40-49 | 1-48 | 6A8 | ATITLE-ZTITLE | Titles for plots. Two cards per plot for two lines of title per plot |
| 50 | 1-10 | F10.3 | WBLX | Ballistic wind in x |
| | 11-20 | | WBLY | Ballistic wind in y |
| | 21-30 | | BFF | Ballistic form factor |
| | 31-40 | | D | Bomb diameter, inches |
| | 41-50 | F10.3 | W | Bomb weight, pounds |
| | 51-53 | I3 | NTB | Number of bombing table to be used |
| 51-... | | | | Bombing table data as supplied with original program; this remains unchanged. |

## APPENDIX C: COARSE GUIDANCE INPUT DATA FORMAT DEFINITION

| CARD | COLUMNS | FORMAT | VARIABLE | REMARKS |
|---|---|---|---|---|
| 1 | 1 | I1 | NLEG | Number of legs |
| | 2-10 | F9.2 | RANGEI | Range of first leg from radar |
| | 11-20 | F10.4 | AZI | Azimuth of first leg from radar |
| | 21-30 | | VA | True airspeed |
| | 31-40 | | VAH | Est. airspeed |
| | 41-50 | | VW | True wind speed |
| | 51-60 | | VWH | Est. wind speed |
| | 61-70 | | THETW | True direction of wind |
| | 71-80 | | THETWH | Est. direction of wind |
| 2 thru NLEG+1 | 1-10 | F10.3 | PLENGTH(i) | Length of the ith leg and its associated azimuth where i=1, NLEG |
| | 11-20 | | THETA(i) | |
| NLEG+2 | 1-10 | | HTG | True initial ground heading |
| | 11-20 | | DELNM(1) | Displacement of true position from RANGEI, AZI in x and y |
| | 21-30 | | DELNM(2) | |
| | 31-40 | | DELNM(3) | DELNM(3) is altitude of aircraft in NM |
| NLEG+3 NLEG+4 | 1-48 | 6A8 | ATITLE | Title for plot of true, estimated and desired paths |

Note: All angles are in degrees from North, clockwise angles positive 0 - 360 degrees. All speeds in ft/sec. All lengths are in nautical miles on entry.

```
                                AN/TPQ-27 SIMULATION

                     PRECISION GUIDANCE MODE WITH KALMAN FILTERING

INITIAL CONDITIONS :

   TRUE WIND AT TARGET =                  0.0            0.0            0.0
   ESTIMATED WIND AT TARGET =             0.0            0.0            0.0

   RADAR DATA
     NUMBER OF NOISY POINTS(NWLD) =      0
     START TIME OF WILD POINTS =         0.0
     MEASUREMENT SIGMAS(R(FT.),AZ(MRAD),EL(MRAD)) =    1.500000 01    1.000000-01    1.000000-01
     MEASUREMENT BIASES(       "                 ) =   0.0            0.0            0.0
     INITIAL VELOCITY MEASUREMENT VALUES =             0.0            0.0            0.0
     RANDOM FORCING ASSUMPTION VALUES (SIGW) =         0.0            0.0            0.0
     RADAR SAMPLING INTERVAL =                         0.1250

   INITIAL POSITION OF A/C IN TARGET SYSTEM =    -3.000000 04    5.000000 03    1.000000 04
   INITIAL VELOCITY OF A/C IN TARGET SYSTEM =     5.000000 02    0.0            0.0


AIRCRAFT PARAMETERS :

    TB =  2.00000       PHB =  0.0


CONTROL PARAMETERS:

    DTCON =  0.12500
    G1 =  75.0000
    G2 =  75.0000


BALLISTIC TABLE PARAMETERS:

    BALLISTIC WIND VALUES (WBLX,WBLY) =   0.0        0.0
    EFF =    1.000000
    D =      4.000000
    W =     23.600000
    NTR =    144


DIVE BOMBING MODE PARAMETERS:

    THO  =      0.0      ATT  =     1.00
    ATH  =      1.00     ANH  =     1.00
    TUP  =      1.00     HTOL =     1.00
   ATOL  =      1.00     THNM =     5.00
   THDM  =      6.00     IB1  =     0
   IACC  =      0



     H ARRAY

   1.00000     0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
   0.0         0.0        0.0        1.00000    0.0        0.0        0.0        0.0        0.0
   0.0         0.0        0.0        0.0        0.0        0.0        1.00000    0.0        0.0
   0.0         0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
   0.0         0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
   0.0         0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
   0.0         0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
   0.0         0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
   0.0         0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
```

GAMMA ARRAY

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.00033 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.00781 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.12500 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.00033 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.00781 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.12500 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.00033 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.00781 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.12500 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

C ARRAY

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

PP ARRAY

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1000000.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 1000000.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 1000000.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 1000000.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 1000000.00000 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1000000.00000 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1000000.00000 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1000000.00000 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1000000.00000 |

PHI ARRAY

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1.0000 | 0.1250 | 0.0078 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 1.0000 | 0.1250 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 1.0000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 1.0000 | 0.1250 | 0.0078 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 1.0000 | 0.1250 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0000 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0000 | 0.1250 | 0.0078 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0000 | 0.1250 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0000 |

R ARRAY

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 959.99368 | 71.15830 | 1.76608 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 71.15830 | 1181.25355 | -18.23060 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.76608 | -18.23060 | 967.02410 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

OUTPUT FORMAT

| X1 X2 X3 X5 X6 PHD1 PH XE | Y1 Y2 Y3 Y5 Y6 PHD2 PHI DXE | Z1 Z2 Z3 Z5 Z6 PHD PHC CTV | XD1 XD2 XD3 XD5 XD6 HDE PS | YD1 YD2 YD3 YD5 YD6 HDEDOT PS1 G(1,1) | ZD1 ZD2 ZD3 ZD5 ZD6 TG G(4,2) | XDD1 TF XGC AA YNP VEH G(7,3) | YDD1 RA YGC HAT THN T |
|---|---|---|---|---|---|---|---|
| -0.29982D 05 | 0.30950D 06 | 0.76753D 04 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| -0.30000D 05 | 0.30950D 06 | 0.77129D 04 | 0.50000D 03 | 0.0 | 0.0 | 0.0 | 0.0 |
| -0.30000D 05 | 0.50000D 04 | 0.10000D 05 | 0.50000D 03 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.30155D-79 | -0.14737D-57 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10000D 04 | 0.85914D-80 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.90000D 02 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.99904D 00 | 0.99882D 00 | 0.99903D 00 | 0.0 |
| -0.29512D 05 | 0.30951D 06 | 0.76900D 04 | 0.46070D 03 | 0.45715D 02 | -0.51560D 02 | -0.10322D 03 | 0.56847D 02 |
| -0.29500D 05 | 0.30950D 06 | 0.77129D 04 | 0.50000D 03 | 0.17437D-12 | -0.25364D-14 | 0.0 | 0.0 |
| -0.29500D 05 | 0.50000D 04 | 0.10000D 05 | 0.50000D 03 | 0.17439D-12 | 0.0 | 0.0 | 0.0 |
| 0.29512D 05 | -0.50146D 04 | -0.99774D 04 | 0.46070D 03 | 0.46460D 02 | -0.50890D 02 | 0.84241D 02 | 0.99774D 04 |
| 0.79505D 04 | 0.28860D 05 | -0.99774D 04 | -0.71054D-14 | 0.46303D 03 | -0.50890D 02 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10000D 04 | 0.46303D 03 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.90000D 02 | 0.84333D 02 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.64524D 00 | 0.64194D 00 | 0.64514D 00 | 0.10000D 01 |
| -0.29020D 05 | 0.30948D 06 | 0.77194D 04 | 0.47374D 03 | -0.24265D 02 | -0.79172D 01 | -0.25066D 02 | -0.18723D 02 |
| -0.29000D 05 | 0.30950D 06 | 0.77129D 04 | 0.50000D 03 | 0.17437D-12 | -0.25364D-14 | 0.0 | 0.0 |
| -0.29000D 05 | 0.50000D 04 | 0.10000D 05 | 0.50000D 03 | 0.17439D-12 | 0.0 | 0.0 | 0.0 |
| 0.29020D 05 | -0.49845D 04 | -0.10006D 05 | 0.47374D 03 | -0.24147D 02 | -0.82693D 01 | 0.92918D 02 | 0.10006D 05 |
| 0.35007D 04 | 0.29237D 05 | -0.10006D 05 | 0.0 | 0.47435D 03 | -0.82693D 01 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10000D 04 | 0.47435D 03 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.90000D 02 | 0.92932D 02 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.42141D 00 | 0.42124D 00 | 0.42144D 00 | 0.20000D 01 |
| -0.28502D 05 | 0.30950D 06 | 0.77156D 04 | 0.50268D 03 | 0.54558D 01 | -0.15093D 02 | -0.10303D 01 | 0.36094D 01 |
| -0.28500D 05 | 0.30950D 06 | 0.77129D 04 | 0.50000D 03 | 0.17437D-12 | -0.25364D-14 | 0.0 | 0.0 |
| -0.28500D 05 | 0.50000D 04 | 0.10000D 05 | 0.50000D 03 | 0.17439D-12 | 0.0 | 0.0 | 0.0 |
| 0.28502D 05 | -0.50002D 04 | -0.10003D 05 | 0.50268D 03 | 0.56747D 01 | -0.15012D 02 | 0.89353D 02 | 0.10003D 05 |
| 0.53216D 04 | 0.28444D 05 | -0.10003D 05 | 0.0 | 0.50271D 03 | -0.15012D 02 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10000D 04 | 0.50271D 03 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.90000D 02 | 0.89378D 02 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.30792D 00 | 0.30788D 00 | 0.30796D 00 | 0.30000D 01 |
| -0.27999D 05 | 0.30949D 06 | 0.77197D 04 | 0.50360D 03 | -0.40607D 00 | -0.11908D 02 | -0.45855D-01 | -0.44679D-01 |
| -0.28000D 05 | 0.30950D 06 | 0.77129D 04 | 0.50000D 03 | 0.17437D-12 | -0.25364D-14 | 0.0 | 0.0 |
| -0.28000D 05 | 0.50000D 04 | 0.10000D 05 | 0.50000D 03 | 0.17439D-12 | 0.0 | 0.0 | 0.0 |
| 0.27999D 05 | -0.49966D 04 | -0.10007D 05 | 0.50360D 03 | -0.23284D 00 | -0.11912D 02 | 0.90026D 02 | 0.10007D 05 |
| 0.49837D 04 | 0.28001D 05 | -0.10007D 05 | 0.0 | 0.50360D 03 | -0.11912D 02 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10000D 04 | 0.50360D 03 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.90000D 02 | 0.90046D 02 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.24213D 00 | 0.24211D 00 | 0.24217D 00 | 0.40000D 01 |
| -0.27506D 05 | 0.30951D 06 | 0.77122D 04 | 0.49375D 03 | 0.98639D 01 | -0.14778D 02 | -0.34462D 01 | 0.30328D 01 |
| -0.27500D 05 | 0.30950D 06 | 0.77129D 04 | 0.50000D 03 | 0.17437D-12 | -0.25364D-14 | 0.0 | 0.0 |
| -0.27500D 05 | 0.50000D 04 | 0.10000D 05 | 0.50000D 03 | 0.17439D-12 | 0.0 | 0.0 | 0.0 |
| 0.27506D 05 | -0.50119D 04 | -0.99995D 04 | 0.49375D 03 | 0.10078D 02 | -0.14633D 02 | 0.88831D 02 | 0.99995D 04 |
| 0.55721D 04 | 0.27398D 05 | -0.99995D 04 | 0.0 | 0.49385D 03 | -0.14633D 02 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10000D 04 | 0.49385D 03 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.90000D 02 | 0.88856D 02 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.19941D 00 | 0.19938D 00 | 0.19945D 00 | 0.50000D 01 |
| -0.27009D 05 | 0.30950D 06 | 0.77191D 04 | 0.49373D 03 | 0.36041D 01 | -0.84222D 01 | -0.25186D 01 | 0.63886D 00 |
| -0.27000D 05 | 0.30950D 06 | 0.77129D 04 | 0.50000D 03 | 0.17437D-12 | -0.25364D-14 | 0.26956D 02 | 0.10853D 05 |
| -0.27000D 05 | 0.50000D 04 | 0.10000D 05 | 0.50000D 03 | 0.17439D-12 | 0.0 | 0.14844D 00 | 0.10873D 05 |
| -0.27009D 05 | 0.50072D 04 | 0.10006D 05 | 0.49373D 03 | 0.37262D 01 | -0.83689D 01 | 0.89568D 02 | 0.10006D 05 |
| 0.87962D 01 | -0.72443D 01 | -0.63331D 01 | 0.62714D 01 | -0.37262D 01 | 0.83689D 01 | 0.0 | 0.0 |
| 0.82013D 03 | 0.0 | 0.82013D 03 | 0.10935D 02 | 0.0 | 0.32603D 02 | 0.49374D 03 | 0.0 |
| 0.0 | 0.0 | 0.29883D 02 | 0.90000D 02 | 0.89582D 02 | 0.0 | 0.0 | 0.0 |
| 0.52108D 04 | 0.0 | -0.93661D 02 | 0.0 | 0.16945D 00 | 0.16943D 00 | 0.16949D 00 | 0.60000D 01 |

OUTPUT FORMAT

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X1 | Y1 | Z1 | XD1 | YD1 | ZD1 | XDD1 | YDD1 |
| X2 | Y2 | Z2 | XD2 | YD2 | ZD2 | TF | RA |
| X3 | Y3 | Z3 | XD3 | YD3 | ZD3 | XGC | YGC |
| X5 | Y5 | Z5 | XD5 | YD5 | ZD5 | AA | HAT |
| X6 | Y6 | Z6 | XD6 | YD6 | ZD6 | YNP | |
| PHD1 | PHD2 | PHD | HDF | HDEDOT | TG | VEH | THN |
| PH | PHI | PHC | PS | PSI | | | |
| XE | DXE | CTV | | G(1,1) | G(4,2) | G(7,3) | T |
| -0.23011D 05 | 0.30917D 06 | 0.77107D 04 | 0.49375D 03 | -0.95321D 02 | -0.71336D 00 | 0.29717D 00 | 0.13734D 00 |
| -0.23021D 05 | 0.30916D 06 | 0.77177D 04 | 0.49059D 03 | -0.96528D 02 | 0.14040D 01 | 0.26955D 02 | 0.11025D 05 |
| -0.23021D 05 | 0.46682D 04 | 0.10000D 05 | 0.49059D 03 | -0.96539D 02 | 0.0 | -0.37226D 01 | 0.11044D 05 |
| -0.23011D 05 | 0.46719D 04 | 0.99931D 04 | 0.49376D 03 | -0.95301D 02 | -0.20996D 01 | 0.10092D 03 | 0.99931D 04 |
| -0.10250D 02 | -0.36845D 01 | 0.69031D 01 | -0.31632D 01 | -0.12376D 01 | 0.20996D 01 | 0.0 | 0.0 |
| 0.42083D 02 | -0.64065D 02 | -0.21982D 02 | 0.56110D 00 | -0.85420D 00 | 0.24729D 02 | 0.50287D 03 | 0.0 |
| 0.13599D 02 | 0.13599D 02 | -0.22031D 02 | 0.10113D 03 | 0.10093D 03 | 0.0 | 0.0 | 0.0 |
| 0.22995D 03 | -0.35589D 03 | -0.49246D 01 | 0.0 | 0.76950D-01 | 0.76920D-01 | 0.76995D-01 | 0.14000D 02 |
| -0.22519D 05 | 0.30907D 06 | 0.77129D 04 | 0.49302D 03 | -0.10015D 03 | -0.65565D-01 | 0.25445D 00 | -0.17706D-01 |
| -0.22531D 05 | 0.30907D 06 | 0.77191D 04 | 0.48988D 03 | -0.10006D 03 | 0.14354D 01 | 0.26957D 02 | 0.11030D 05 |
| -0.22531D 05 | 0.45692D 04 | 0.10000D 05 | 0.48983D 03 | -0.10007D 03 | 0.0 | -0.29105D 01 | 0.11049D 05 |
| -0.22519D 05 | 0.45685D 04 | 0.99938D 04 | 0.49302D 03 | -0.10014D 03 | -0.15222D 01 | 0.10148D 03 | 0.99938D 04 |
| -0.12651D 02 | 0.69047D 00 | 0.62077D 01 | -0.31339D 01 | 0.69201D-01 | 0.15222D 01 | 0.0 | 0.0 |
| -0.26803D 00 | -0.30583D 02 | -0.30851D 02 | -0.35737D-02 | -0.40777D 00 | 0.23711D 02 | 0.50308D 03 | 0.0 |
| 0.10878D 01 | 0.10878D 01 | -0.30000D 02 | 0.10155D 03 | 0.10148D 03 | 0.0 | 0.0 | 0.0 |
| -0.14332D 01 | -0.16393D 03 | 0.31379D-01 | 0.0 | 0.72042D-01 | 0.72011D-01 | 0.72085D-01 | 0.15000D 02 |
| -0.22038D 05 | 0.30897D 06 | 0.77153D 04 | 0.49031D 03 | -0.99669D 02 | 0.49847D 00 | -0.42301D-01 | 0.57397D-01 |
| -0.22042D 05 | 0.30897D 06 | 0.77206D 04 | 0.48983D 03 | -0.10031D 03 | 0.14591D 01 | 0.26953D 02 | 0.10976D 05 |
| -0.22042D 05 | 0.44690D 04 | 0.10000D 05 | 0.48963D 03 | -0.10032D 03 | 0.0 | -0.39130D 01 | 0.10995D 05 |
| -0.22038D 05 | 0.44714D 04 | 0.99947D 04 | 0.49031D 03 | -0.99665D 02 | -0.95115D 00 | 0.10149D 03 | 0.99947D 04 |
| -0.37729D 01 | -0.24288D 01 | 0.52975D 01 | -0.47399D 00 | -0.65564D 00 | 0.95115D 00 | 0.0 | 0.0 |
| -0.79422D 00 | 0.34415D 01 | 0.26472D 01 | -0.10590D-01 | 0.45896D-01 | 0.22968D 02 | 0.50033D 03 | 0.0 |
| -0.82275D 00 | -0.82275D 00 | 0.26953D 01 | 0.10157D 03 | 0.10149D 03 | 0.0 | 0.0 | 0.0 |
| -0.41561D 01 | 0.18147D 02 | 0.92474D-01 | 0.0 | 0.67723D-01 | 0.67691D-01 | 0.67765D-01 | 0.16000D 02 |
| -0.21542D 05 | 0.30887D 06 | 0.77117D 04 | 0.49154D 03 | -0.99652D 02 | -0.35893D 00 | 0.84361D-01 | 0.67743D-01 |
| -0.21552D 05 | 0.30887D 06 | 0.77221D 04 | 0.48980D 03 | -0.10047D 03 | 0.14613D 01 | 0.26948D 02 | 0.10997D 05 |
| -0.21552D 05 | 0.43686D 04 | 0.10000D 05 | 0.48980D 03 | -0.10048D 03 | 0.0 | -0.38958D 01 | 0.11016D 05 |
| -0.21542D 05 | 0.43724D 04 | 0.99897D 04 | 0.49154D 03 | -0.99636D 02 | -0.18082D 01 | 0.10146D 03 | 0.99897D 04 |
| -0.99362D 01 | -0.37587D 01 | 0.10265D 02 | -0.17427D 01 | -0.84166D 00 | 0.18032D 01 | 0.0 | 0.0 |
| 0.18796D 01 | 0.53082D 01 | 0.71873D 01 | 0.25061D-01 | 0.70776D-01 | 0.21862D 02 | 0.50154D 03 | 0.0 |
| 0.92057D-01 | 0.82057D-01 | 0.71484D 01 | 0.10159D 03 | 0.10146D 03 | 0.0 | 0.0 | 0.0 |
| 0.96144D 01 | 0.27005D 02 | -0.21937D 00 | 0.0 | 0.63890D-01 | 0.63856D-01 | 0.63934D-01 | 0.17000D 02 |
| -0.21053D 05 | 0.30877D 06 | 0.77150D 04 | 0.49114D 03 | -0.99851D 02 | 0.39059D 00 | 0.32157D-01 | 0.15002D-01 |
| -0.21062D 05 | 0.30876D 06 | 0.77235D 04 | 0.48987D 03 | -0.10014D 03 | 0.14566D 01 | 0.26950D 02 | 0.10991D 05 |
| -0.21062D 05 | 0.42682D 04 | 0.10000D 05 | 0.48987D 03 | -0.10016D 03 | 0.0 | -0.39116D 01 | 0.11010D 05 |
| -0.21053D 05 | 0.42700D 04 | 0.99915D 04 | 0.49114D 03 | -0.99846D 02 | -0.10617D 01 | 0.101[illegible]D 03 | 0.99915D 04 |
| -0.93055D 01 | -0.17518D 01 | 0.85174D 01 | -0.12712D 01 | -0.30881D 00 | 0.10617D 01 | 0.0 | 0.0 |
| -0.11621D 01 | -0.93954D 01 | -0.10558D 02 | -0.15494D-01 | -0.12527D 00 | 0.20853D 02 | 0.50118D 03 | 0.0 |
| 0.67533D-01 | 0.67533D-01 | -0.10547D 02 | 0.10156D 03 | 0.10149D 03 | 0.0 | 0.0 | 0.0 |
| -0.58090D 01 | -0.46966D 02 | 0.13553D 00 | 0.0 | 0.60473D-01 | 0.60439D-01 | 0.60513D-01 | 0.18000D 02 |
| -0.20568D 05 | 0.30867D 06 | 0.77229D 04 | 0.49002D 03 | -0.99318D 02 | 0.14329D 01 | -0.80905D-01 | -0.27461D-02 |
| -0.20572D 05 | 0.30867D 06 | 0.77250D 04 | 0.49002D 03 | -0.99412D 02 | 0.14460D 01 | 0.26957D 02 | 0.10971D 05 |
| -0.20572D 05 | 0.41685D 04 | 0.10000D 05 | 0.49002D 03 | -0.99423D 02 | 0.0 | -0.39046D 01 | 0.10990D 05 |
| -0.20569D 05 | 0.41693D 04 | 0.99979D 04 | 0.49002D 03 | -0.99336D 02 | 0.48818D 00 | 0.10146D 03 | 0.99979D 04 |
| -0.43736D 01 | -0.83104D 00 | 0.20781D 01 | -0.60758D-02 | -0.87399D-01 | -0.48818D 00 | 0.0 | 0.0 |
| 0.77830D 00 | 0.30388D 02 | 0.31166D 02 | 0.10377D-01 | 0.40517D 00 | 0.19992D 02 | 0.49999D 03 | 0.0 |
| -0.22920D 01 | -0.22920D 01 | 0.29883D 02 | 0.10147D 03 | 0.10146D 03 | 0.0 | 0.0 | 0.0 |
| 0.38009D 01 | 0.14874D 03 | -0.90557D-01 | 0.0 | 0.57399D-01 | 0.57365D-01 | 0.57440D-01 | 0.19000D 02 |
| -0.20075D 05 | 0.30857D 06 | 0.77231D 04 | 0.49040D 03 | -0.99560D 02 | 0.17343D 01 | -0.43384D-01 | -0.19218D-01 |
| -0.20082D 05 | 0.30957D 06 | 0.77264D 04 | 0.49001D 03 | -0.99450D 02 | 0.14465D 01 | 0.26956D 02 | 0.10978D 05 |
| -0.20082D 05 | 0.40691D 04 | 0.10000D 05 | 0.49001D 03 | -0.99461D 02 | 0.0 | -0.39101D 01 | 0.10998D 05 |
| -0.20075D 05 | 0.40690D 04 | 0.99967D 04 | 0.49040D 03 | -0.99574D 02 | 0.28614D 00 | 0.10143D 03 | 0.99967D 04 |
| -0.68446D 01 | 0.97033D-01 | 0.32873D 01 | -0.39272D 00 | 0.11369D 00 | -0.28614D 00 | 0.0 | 0.0 |
| -0.65837D 00 | -0.19607D 02 | -0.11266D 02 | -0.87783D-02 | -0.14143D 00 | 0.18956D 02 | 0.50041D 03 | 0.0 |
| 0.10551D 00 | 0.10551D 00 | -0.11250D 02 | 0.10147D 03 | 0.10148D 03 | 0.0 | 0.0 | 0.0 |
| -0.31383D 01 | -0.50640D 02 | 0.76668D-01 | 0.0 | 0.54623D-01 | 0.54589D-01 | 0.54664D-01 | 0.20000D 02 |

OUTPUT FORMAT

| X1<br>X2<br>X3<br>X5<br>X6<br>PHD1<br>PH<br>XE | Y1<br>Y2<br>Y3<br>Y5<br>Y6<br>PHD2<br>PH1<br>DXE | Z1<br>Z2<br>Z3<br>Z5<br>Z6<br>PHD<br>PHC<br>CTV | XD1<br>XD2<br>XD3<br>XD5<br>XD6<br>HOE<br>PS | YD1<br>YD2<br>YD3<br>YD5<br>YD6<br>HOEDC?<br>PS1<br>G(1,1) | ZD1<br>ZD2<br>ZD3<br>ZD5<br>ZD6<br>TG<br>G(4,2) | XDD1<br>TF<br>XGC<br>AA<br>YNP<br>VEH<br>G(7,3) | YDD1<br>RA<br>YGC<br>HAT<br>THN<br>T |
|---|---|---|---|---|---|---|---|
| -0.19584D 05 | 0.30847D 06 | 0.77264D 04 | 0.48955D 03 | -0.99846D 02 | 0.21554D 01 | -0.10496D 00 | -0.27335D-01 |
| -0.19592D 05 | 0.30847D 06 | 0.77279D 04 | 0.48997D 03 | -0.99621D 02 | 0.14490D 01 | 0.26957D 02 | 0.10964D 05 |
| -0.19592D 05 | 0.39696D 04 | 0.10000D 05 | 0.48997D 03 | -0.99631D 02 | 0.0 | -0.39286D 01 | 0.10983D 05 |
| -0.19584D 05 | 0.39689D 04 | 0.99986D 04 | 0.48955D 03 | -0.99867D 02 | 0.70301D 00 | 0.10153D 03 | 0.99986D 04 |
| -0.31835D 01 | 0.69352D 00 | 0.14392D 01 | 0.42457D 00 | 0.23583D 00 | -0.70301D 00 | 0.0 | 0.0 |
| -0.48776D 01 | -0.36189D 02 | -0.41066D 02 | -0.65035D-01 | -0.48251D 00 | 0.18020D 02 | 0.49963D 03 | 0.0 |
| -0.15960D 00 | -0.15960D 00 | -0.30000D 02 | 0.10149D 03 | 0.10153D 03 | 0.0 | 0.0 | 0.0 |
| -0.22686D 02 | -0.16828D 03 | 0.56712D 00 | 0.0 | 0.52106D-01 | 0.52072D-01 | 0.52145D-01 | 0.21000D 02 |
| -0.19094D 05 | 0.30837D 06 | 0.77176D 04 | 0.49042D 03 | -0.99070D 02 | 0.36763D 00 | -0.39233D-01 | -0.53149D-02 |
| -0.19102D 05 | 0.30837D 06 | 0.77293D 04 | 0.49008D 03 | -0.99108D 02 | 0.14416D 01 | 0.26943D 02 | 0.10972D 05 |
| -0.19102D 05 | 0.38704D 04 | 0.10000D 05 | 0.49008D 03 | -0.99118D 02 | 0.0 | -0.38857D 01 | 0.10992D 05 |
| -0.19094D 05 | 0.38712D 04 | 0.99883D 04 | 0.49042D 03 | -0.99065D 02 | -0.10733D 01 | 0.10142D 03 | 0.99883D 04 |
| -0.74823D 01 | -0.81379D 00 | 0.11709D 02 | -0.33956D 00 | -0.53384D-01 | 0.10733D 01 | 0.0 | 0.0 |
| 0.38972D 01 | -0.24445D 01 | 0.14526D 01 | 0.51962D-01 | -0.32594D-01 | 0.16972D 02 | 0.50032D 03 | 0.0 |
| 0.20203D 01 | 0.20203D 01 | 0.14063D 01 | 0.10143D 03 | 0.10142D 03 | 0.0 | 0.0 | 0.0 |
| 0.17669D 02 | -0.11583D 02 | -0.45375D 00 | 0.0 | 0.49808D-01 | 0.49773D-01 | 0.49849D-01 | 0.22000D 02 |
| -0.18608D 05 | 0.30827D 06 | 0.77333D 04 | 0.48958D 03 | -0.99629D 02 | 0.29839D 01 | -0.84841D-01 | 0.10817D-01 |
| -0.18612D 05 | 0.30827D 06 | 0.77308D 04 | 0.48992D 03 | -0.99895D 02 | 0.14530D 01 | 0.26963D 02 | 0.10966D 05 |
| -0.18612D 05 | 0.37707D 04 | 0.10000D 05 | 0.48992D 03 | -0.99905D 02 | 0.0 | -0.39230D 01 | 0.10985D 05 |
| -0.18608D 05 | 0.37728D 04 | 0.10003D 05 | 0.48958D 03 | -0.99662D 02 | 0.15346D 01 | 0.10151D 03 | 0.10003D 05 |
| -0.40084D 01 | -0.21026D 01 | -0.25812D 01 | 0.33908D 00 | -0.24329D 00 | -0.15346D 01 | 0.0 | 0.0 |
| -0.24750D 01 | 0.80756D 00 | -0.16674D 01 | -0.33000D-01 | 0.10768D-01 | 0.16015D 02 | 0.49962D 03 | 0.0 |
| -0.98708D 00 | -0.98708D 00 | -0.16406D 01 | 0.10153D 03 | 0.10150D 03 | 0.0 | 0.0 | 0.0 |
| -0.10935D 02 | 0.38636D 01 | 0.28776D 00 | 0.0 | 0.47708D-01 | 0.47673D-01 | 0.47747D-01 | 0.23000D 02 |
| -0.18112D 05 | 0.30817D 06 | 0.77399D 04 | 0.49055D 03 | -0.99592D 02 | 0.37824D 01 | -0.11940D-01 | 0.18652D-01 |
| -0.18122D 05 | 0.30817D 06 | 0.77322D 04 | 0.48990D 03 | -0.99982D 02 | 0.14543D 01 | 0.26972D 02 | 0.10987D 05 |
| -0.18122D 05 | 0.36709D 04 | 0.10000D 05 | 0.48990D 03 | -0.99993D 02 | 0.0 | -0.39181D 01 | 0.11006D 05 |
| -0.18112D 05 | 0.36739D 04 | 0.10008D 05 | 0.49055D 03 | -0.99637D 02 | 0.23335D 01 | 0.10148D 03 | 0.10008D 05 |
| -0.10319D 02 | -0.29398D 01 | -0.77872D 01 | -0.64869D 00 | -0.35604D 00 | -0.23335D 01 | 0.0 | 0.0 |
| -0.19540D 00 | -0.17711D 02 | -0.17906D 02 | -0.26053D-02 | -0.23615D 00 | 0.14932D 02 | 0.50056D 03 | 0.0 |
| 0.10869D 01 | 0.10668D 01 | -0.17930D 02 | 0.10154D 03 | 0.10148D 03 | 0.0 | 0.0 | 0.0 |
| -0.84033D 00 | -0.76404D 02 | 0.22761D-01 | 0.0 | 0.45776D-01 | 0.45741D-01 | 0.45815D-01 | 0.24000D 02 |
| -0.17618D 05 | 0.30807D 06 | 0.77431D 04 | 0.49103D 03 | -0.99536D 02 | 0.39035D 01 | 0.20149D-01 | 0.16676D-01 |
| -0.17632D 05 | 0.30807D 06 | 0.77337D 04 | 0.48991D 03 | -0.99944D 02 | 0.14537D 01 | 0.2[illegible]976D 02 | 0.10997D 05 |
| -0.17632D 05 | 0.35709D 04 | 0.10000D 05 | 0.48991D 03 | -0.99954D 02 | 0.0 | -0.3[illegible]135D 01 | 0.11016D 05 |
| -0.17618D 05 | 0.35742D 04 | 0.10010D 05 | 0.49103D 03 | -0.99582D 02 | 0.24554D 01 | 0.10146D 03 | 0.10010D 05 |
| -0.13996D 02 | -0.33488D 01 | -0.95141D 01 | -0.11199D 01 | -0.37228D 00 | -0.24554D 01 | 0.0 | 0.0 |
| 0.12176D 01 | 0.12843D 02 | 0.14061D 02 | 0.16235D-01 | 0.17124D 00 | 0.13893D 02 | 0.50102D 03 | 0.0 |
| -0.23330D 00 | -0.23330D 00 | 0.14063D 02 | 0.10153D 03 | 0.10146D 03 | 0.0 | 0.0 | 0.0 |
| 0.50937D 01 | 0.53774D 02 | -0.14196D 00 | 0.0 | 0.43995D-01 | 0.43960D-01 | 0.44033D-01 | 0.25000D 02 |
| -0.17123D 05 | 0.30797D 06 | 0.77439D 04 | 0.49169D 03 | -0.99434D 02 | 0.36470D 01 | 0.63460D-01 | 0.37146D-01 |
| -0.17142D 05 | 0.30797D 06 | 0.77351D 04 | 0.48987D 03 | -0.10015D 03 | 0.14567D 01 | 0.26976D 02 | 0.11009D 05 |
| -0.17142D 05 | 0.34709D 04 | 0.10000D 05 | 0.48987D 03 | -0.10016D 03 | 0.0 | -0.39042D 01 | 0.11028D 05 |
| -0.17123D 05 | 0.34765D 04 | 0.10009D 05 | 0.49169D 03 | -0.99477D 02 | 0.22004D 01 | 0.10144D 03 | 0.10009D 05 |
| -0.19624D 02 | -0.56046D 01 | -0.88289D 01 | -0.18220D 01 | -0.68058D 00 | -0.22004D 01 | 0.0 | 0.0 |
| 0.39287D 01 | 0.65998D 00 | 0.45887D 01 | 0.52383D-01 | 0.87998D-02 | 0.12845D 02 | 0.50165D 03 | 0.0 |
| 0.21751D 01 | 0.21751D 01 | 0.45703D 01 | 0.10156D 03 | 0.10143D 03 | 0.0 | 0.0 | 0.0 |
| 0.15974D 02 | 0.22404D 01 | -0.45863D 00 | 0.0 | 0.42349D-01 | 0.42314D-01 | 0.42386D-01 | 0.26000D 02 |
| -0.16634D 05 | 0.30787D 06 | 0.77448D 04 | 0.49130D 03 | -0.99702D 02 | 0.34407D 01 | 0.36572D-01 | 0.20571D-01 |
| -0.16652D 05 | 0.30787D 06 | 0.77366D 04 | 0.48986D 03 | -0.10018D 03 | 0.14571D 01 | 0.26975D 02 | 0.11002D 05 |
| -0.16652D 05 | 0.33706D 04 | 0.10000D 05 | 0.48986D 03 | -0.10019D 03 | 0.0 | -0.39168D 01 | 0.11021D 05 |
| -0.16634D 05 | 0.33750D 04 | 0.10008D 05 | 0.49130D 03 | -0.99742D 02 | 0.19902D 01 | 0.10148D 03 | 0.10008D 05 |
| -0.18369D 02 | -0.44059D 01 | -0.83356D 01 | -0.14415D 01 | -0.44596D 00 | -0.19902D 01 | 0.0 | 0.0 |
| 0.50223D 00 | 0.68027D 01 | 0.73049D 01 | 0.66965D-02 | 0.90702D-01 | 0.11871D 02 | 0.50132D 03 | 0.0 |
| -0.18156D 00 | -0.18156D 00 | 0.72656D 01 | 0.10156D 03 | 0.10147D 03 | 0.0 | 0.0 | 0.0 |
| 0.19837D 01 | 0.26910D 02 | -0.58592D-01 | 0.0 | 0.40821D-01 | 0.40786D-01 | 0.40858D-01 | 0.27000D 02 |

OUTPUT FORMAT

| X1<br>X2<br>X3<br>X5<br>X6<br>PHD1<br>PH<br>XE | Y1<br>Y2<br>Y3<br>Y5<br>Y6<br>PHD2<br>PH1<br>DXE | Z1<br>Z2<br>Z3<br>Z5<br>Z6<br>PHD<br>PHC<br>CTV | XD1<br>XD2<br>XD3<br>XD5<br>XD6<br>HDE<br>PS | YD1<br>YD2<br>YD3<br>YD5<br>YD6<br>HDEDCT<br>PSI<br>G(1,1) | ZD1<br>ZD2<br>ZD3<br>ZD5<br>ZD6<br>TG<br>G(4,2) | XDD1<br>TF<br>XGC<br>AA<br>YNP<br>VEH<br>G(7,3) | YDD1<br>RA<br>YGC<br>HAT<br>THN<br>T |
|---|---|---|---|---|---|---|---|
| -0.16149D 05 | 0.30777D 06 | 0.77465D 04 | 0.49042D 03 | -0.99618D 02 | 0.33505D 01 | -0.19466D-01 | 0.15658D-01 |
| -0.16162D 05 | 0.30777D 06 | 0.77380D 04 | 0.48989D 03 | -0.10003D 03 | 0.14550D 01 | 0.26973D 02 | 0.10985D 05 |
| -0.16162D 05 | 0.32704D 04 | 0.10000D 05 | 0.48989D 03 | -0.10004D 03 | 0.0 | -0.39202D 01 | 0.11004D 05 |
| -0.16149D 05 | 0.32747D 04 | 0.10009D 05 | 0.49042D 03 | -0.99656D 02 | 0.19014D 01 | 0.10149D 03 | 0.10009D 05 |
| -0.13093D 02 | -0.43078D 01 | -0.85609D 01 | -0.52889D 00 | -0.38533D 00 | -0.19014D 01 | 0.0 | 0.0 |
| -0.76109D 00 | 0.13911D 02 | 0.13149D 02 | -0.10148D-01 | 0.18547D 00 | 0.10938D 02 | 0.50044D 03 | 0.0 |
| -0.14407D 01 | -0.14407D 01 | 0.13125D 02 | 0.10154D 03 | 0.10148D 03 | 0.0 | 0.0 | 0.0 |
| -0.29184D 01 | 0.53631D 02 | 0.88634D-01 | 0.0 | 0.39400D-01 | 0.39365D-01 | 0.39436D-01 | 0.28000D 02 |
| -0.15659D 05 | 0.30767D 06 | 0.77457D 04 | 0.49041D 03 | -0.99521D 02 | 0.29450D 01 | -0.19295D-01 | 0.18552D-01 |
| -0.15673D 05 | 0.30767D 06 | 0.77395D 04 | 0.48990D 03 | -0.10000D 03 | 0.14545D 01 | 0.26970D 02 | 0.10983D 05 |
| -0.15673D 05 | 0.31704D 04 | 0.10000D 05 | 0.48990D 03 | -0.10001D 03 | 0.0 | -0.39150D 01 | 0.11002D 05 |
| -0.15659D 05 | 0.31756D 04 | 0.10006D 05 | 0.49041D 03 | -0.99553D 02 | 0.14973D 01 | 0.10148D 03 | 0.10006D 05 |
| -0.13668D 02 | -0.51279D 01 | -0.62982D 01 | -0.51398D 00 | -0.45733D 00 | -0.14973D 01 | 0.0 | 0.0 |
| 0.21053D 00 | 0.48408D 01 | 0.50513D 01 | 0.28070D-02 | 0.64544D-01 | 0.99422D 01 | 0.50041D 03 | 0.0 |
| -0.24036D 00 | -0.24036D 00 | 0.50391D 01 | 0.10154D 03 | 0.10147D 03 | 0.0 | 0.0 | 0.0 |
| 0.78277D 00 | 0.18045D 02 | -0.24516D-01 | 0.0 | 0.38075D-01 | 0.38039D-01 | 0.38110D-01 | 0.29000D 02 |
| -0.15177D 05 | 0.30757D 06 | 0.77430D 04 | 0.48942D 03 | -0.99332D 02 | 0.29878D 01 | -0.78729D-01 | -0.14148D-02 |
| -0.15183D 05 | 0.30757D 06 | 0.77409D 04 | 0.49000D 03 | -0.99468D 02 | 0.14468D 01 | 0.26969D 02 | 0.10964D 05 |
| -0.15183D 05 | 0.30706D 04 | 0.10000D 05 | 0.49000D 03 | -0.99478D 02 | 0.0 | -0.39158D 01 | 0.10983D 05 |
| -0.15177D 05 | 0.30734D 04 | 0.10007D 05 | 0.48942D 03 | -0.99365D 02 | 0.15428D 01 | 0.10148D 03 | 0.10007D 05 |
| -0.58748D 01 | -0.28379D 01 | -0.71356D 01 | 0.58810D 00 | -0.11271D 00 | -0.15428D 01 | 0.0 | 0.0 |
| -0.10579D 01 | 0.78867D 01 | 0.68287D 01 | -0.14106D-01 | 0.10516D 00 | 0.90146D 01 | 0.49940D 03 | 0.0 |
| -0.14119D 01 | -0.14119D 01 | 0.67969D 01 | 0.10148D 03 | 0.10147D 03 | 0.0 | 0.0 | 0.0 |
| -0.38123D 01 | 0.28650D 02 | 0.12295D 00 | 0.0 | 0.36837D-01 | 0.36802D-01 | 0.36871D-01 | 0.30000D 02 |
| -0.14689D 05 | 0.30747D 06 | 0.77444D 04 | 0.48922D 03 | -0.99237D 02 | 0.22588D 01 | -0.86657D-01 | -0.63324D-02 |
| -0.14693D 05 | 0.30747D 06 | 0.77424D 04 | 0.49004D 03 | -0.99279D 02 | 0.14441D 01 | 0.26961D 02 | 0.10957D 05 |
| -0.14693D 05 | 0.29713D 04 | 0.10000D 05 | 0.49004D 03 | -0.99290D 02 | 0.0 | -0.39101D 01 | 0.10976D 05 |
| -0.14689D 05 | 0.29736D 04 | 0.10002D 05 | 0.48922D 03 | -0.99259D 02 | 0.81524D 00 | 0.10147D 03 | 0.10002D 05 |
| -0.40230D 01 | -0.23518D 01 | -0.20647D 01 | 0.81786D 00 | -0.31015D-01 | -0.81524D 00 | 0.0 | 0.0 |
| -0.71844D 00 | -0.58500D 01 | -0.65685D 01 | -0.95791D-02 | -0.78000D-01 | 0.80336D 01 | 0.49919D 03 | 0.0 |
| -0.18625D 00 | -0.18625D 00 | -0.65625D 01 | 0.10145D 03 | 0.10147D 03 | 0.0 | 0.0 | 0.0 |
| -0.25056D 01 | -0.20404D 02 | 0.33459D-01 | 0.0 | 0.35675D-01 | 0.35641D-01 | 0.35710D-01 | 0.31000D 02 |
| -0.14201D 05 | 0.30737D 06 | 0.77461D 04 | 0.48902D 03 | -0.98978D 02 | 0.22570D 01 | -0.94656D-01 | -0.18487D-02 |
| -0.14203D 05 | 0.30737D 06 | 0.77438D 04 | 0.49008D 03 | -0.99101D 02 | 0.14415D 01 | 0.26961D 02 | 0.10952D 05 |
| -0.14203D 05 | 0.28721D 04 | 0.10000D 05 | 0.49008D 03 | -0.99112D 02 | 0.0 | -0.39019D 01 | 0.10971D 05 |
| -0.14201D 05 | 0.28752D 04 | 0.10002D 05 | 0.48902D 03 | -0.99000D 02 | 0.81723D 00 | 0.10144D 03 | 0.10002D 05 |
| -0.18151D 01 | -0.30959D 01 | -0.22845D 01 | 0.10630D 01 | -0.11162D 00 | -0.81723D 00 | 0.0 | 0.0 |
| 0.12391D 01 | 0.36927D 01 | 0.49318D 01 | 0.16522D-01 | 0.49236D-01 | 0.70501D 01 | 0.49894D 03 | 0.0 |
| 0.25394D 00 | 0.25394D 00 | 0.49219D 01 | 0.10143D 03 | 0.10144D 03 | 0.0 | 0.0 | 0.0 |
| 0.41780D 01 | 0.12358D 02 | -0.14387D 00 | 0.0 | 0.34586D-01 | 0.34551D-01 | 0.34620D-01 | 0.32000D 02 |
| -0.13717D 05 | 0.30727D 06 | 0.77471D 04 | 0.48826D 03 | -0.98926D 02 | 0.21784D 01 | -0.12696D 00 | 0.37521D-02 |
| -0.13712D 05 | 0.30727D 06 | 0.77453D 04 | 0.49007D 03 | -0.99161D 02 | 0.14423D 01 | 0.26959D 02 | 0.10937D 05 |
| -0.13712D 05 | 0.27729D 04 | 0.10000D 05 | 0.49007D 03 | -0.99171D 02 | 0.0 | -0.39053D 01 | 0.10956D 05 |
| -0.13717D 05 | 0.27771D 04 | 0.10002D 05 | 0.48826D 03 | -0.98947D 02 | 0.73939D 00 | 0.10145D 03 | 0.10002D 05 |
| 0.47513D 01 | -0.41843D 01 | -0.19221D 01 | 0.18042D 01 | -0.22385D 00 | -0.73939D 00 | 0.0 | 0.0 |
| 0.37850D 00 | 0.56547D 01 | 0.60332D 01 | 0.50467D-02 | 0.75396D-01 | 0.61004D 01 | 0.49819D 03 | 0.0 |
| -0.22486D 00 | -0.22486D 00 | 0.59766D 01 | 0.10144D 03 | 0.10145D 03 | 0.0 | 0.0 | 0.0 |
| 0.12328D 01 | 0.18454D 02 | -0.43881D-01 | 0.0 | 0.33562D-01 | 0.33527D-01 | 0.33594D-01 | 0.33000D 02 |
| -0.13227D 05 | 0.30717D 06 | 0.77495D 04 | 0.48837D 03 | -0.98997D 02 | 0.22736D 01 | -0.11633D 00 | -0.31420D-02 |
| -0.13222D 05 | 0.30717D 06 | 0.77467D 04 | 0.49008D 03 | -0.99093D 02 | 0.14414D 01 | 0.26961D 02 | 0.10940D 05 |
| -0.13222D 05 | 0.26737D 04 | 0.10000D 05 | 0.49008D 03 | -0.99104D 02 | 0.0 | -0.39078D 01 | 0.10959D 05 |
| -0.13227D 05 | 0.26769D 04 | 0.10003D 05 | 0.48837D 03 | -0.99020D 02 | 0.83351D 00 | 0.10146D 03 | 0.10003D 05 |
| 0.47238D 01 | -0.31712D 01 | -0.28730D 01 | 0.17128D 01 | -0.83868D-01 | -0.83351D 00 | 0.0 | 0.0 |
| -0.30920D 00 | -0.72706D 00 | -0.10363D 01 | -0.41227D-02 | -0.96942D-02 | 0.50896D 01 | 0.49830D 03 | 0.0 |
| -0.18564D 00 | -0.18564D 00 | -0.10547D 01 | 0.10143D 03 | 0.10146D 03 | 0.0 | 0.0 | 0.0 |
| -0.97105D 00 | -0.22580D 01 | 0.35855D-01 | 0.0 | 0.32596D-01 | 0.32562D-01 | 0.32628D-01 | 0.34000D 02 |

OUTPUT FORMAT

| X1 | Y1 | Z1 | XD1 | YD1 | ZD1 | XDD1 | YDD1 |
|---|---|---|---|---|---|---|---|
| X2 | Y2 | Z2 | XD2 | YD2 | ZD2 | TF | RA |
| X3 | Y3 | Z3 | XD3 | YD3 | ZD3 | XGC | YGC |
| X5 | Y5 | Z5 | XD5 | YD5 | ZD5 | AA | HAT |
| X6 | Y6 | Z6 | XD6 | YD6 | ZD6 | YNP | |
| PHO1 | PHO2 | PHO | HDE | HDEDOT | T3 | VEH | THN |
| PH | PHI | PHC | PS | PS1 | | | |
| XE | DXE | CTV | | G(1,1) | G(4,2) | G(7,3) | T |
| | | | | | | | |
| -0.12740D 05 | 0.30707D 06 | 0.77503D 04 | 0.48818D 03 | -0.98821D 02 | 0.21658D 01 | -0.12333D 00 | -0.14183D-01 |
| -0.12732D 05 | 0.30707D 06 | 0.77481D 04 | 0.49016D 03 | -0.98678D 02 | 0.14353D 01 | 0.26959D 02 | 0.10935D 05 |
| -0.12732D 05 | 0.25749D 04 | 0.10000D 05 | 0.49016D 03 | -0.98689D 02 | 0.0 | -0.39020D 01 | 0.10955D 05 |
| -0.12740D 05 | 0.25760D 04 | 0.10002D 05 | 0.48818D 03 | -0.98842D 02 | 0.72838D 00 | 0.10145D 03 | 0.10002D 05 |
| 0.78672D 01 | -0.11625D 01 | -0.22162D 01 | 0.19790D 01 | 0.15296D 00 | -0.72838D 00 | 0.0 | 0.0 |
| 0.17357D 00 | 0.19434D 01 | 0.21170D 01 | 0.23142D-02 | 0.25912D-01 | 0.41025D 01 | 0.49809D 03 | 0.0 |
| -0.26258D 00 | -0.26258D 00 | 0.21094D 01 | 0.10138D 03 | 0.10144D 03 | 0.0 | 0.0 | 0.0 |
| 0.52499D 00 | 0.58865D 01 | -0.20118D-01 | 0.0 | 0.31685D-01 | 0.31650D-01 | 0.31716D-01 | 0.35000D 02 |
| | | | | | | | |
| -0.12248D 05 | 0.30697D 06 | 0.77542D 04 | 0.48856D 03 | -0.98866D 02 | 0.24057D 01 | -0.10142D 00 | -0.20932D-01 |
| -0.12242D 05 | 0.30697D 06 | 0.77496D 04 | 0.49019D 03 | -0.98562D 02 | 0.14336D 01 | 0.26964D 02 | 0.10944D 05 |
| -0.12242D 05 | 0.24762D 04 | 0.10000D 05 | 0.49019D 03 | -0.98573D 02 | 0.0 | -0.39026D 01 | 0.10963D 05 |
| -0.12248D 05 | 0.24758D 04 | 0.10005D 05 | 0.48856D 03 | -0.98691D 02 | 0.96758D 00 | 0.10144D 03 | 0.10005D 05 |
| 0.56016D 01 | 0.38472D 00 | -0.46421D 01 | 0.16270D 01 | 0.31849D 00 | -0.96758D 00 | 0.0 | 0.0 |
| 0.23939D 00 | 0.72512D 00 | 0.96451D 00 | 0.31918D-02 | 0.96682D-02 | 0.30738D 01 | 0.49847D 03 | 0.0 |
| -0.83915D-01 | -0.83915D-01 | 0.93750D 00 | 0.10137D 03 | 0.10144D 03 | 0.0 | 0.0 | 0.0 |
| 0.69609D 00 | 0.20909D 01 | -0.27769D-01 | 0.0 | 0.30823D-01 | 0.30789D-01 | 0.30854D-01 | 0.36000D 02 |
| | | | | | | | |
| -0.11755D 05 | 0.30687D 06 | 0.77509D 04 | 0.48887D 03 | -0.98939D 02 | 0.18622D 01 | -0.81744D-01 | -0.17010D-01 |
| -0.11752D 05 | 0.30687D 06 | 0.77510D 04 | 0.49016D 03 | -0.98701D 02 | 0.14356D 01 | 0.26957D 02 | 0.10948D 05 |
| -0.11752D 05 | 0.23776D 04 | 0.10000D 05 | 0.49016D 03 | -0.98711D 02 | 0.0 | -0.38999D 01 | 0.10967D 05 |
| -0.11755D 05 | 0.23778D 04 | 0.99999D 04 | 0.48887D 03 | -0.98956D 02 | 0.42305D 00 | 0.10144D 03 | 0.99999D 04 |
| 0.31500D 01 | -0.16153D 00 | 0.78856D-01 | 0.12883D 01 | 0.24494D 00 | -0.42305D 00 | 0.0 | 0.0 |
| 0.82320D 00 | -0.10009D 02 | -0.91855D 01 | 0.10976D-01 | -0.13345D 00 | 0.20571D 01 | 0.49875D 03 | 0.0 |
| 0.11379D 01 | 0.11379D 01 | -0.91406D 01 | 0.10139D 03 | 0.10144D 03 | 0.0 | 0.0 | 0.0 |
| 0.22975D 01 | -0.28175D 02 | -0.95552D-01 | 0.0 | 0.30007D-01 | 0.29973D-01 | 0.30038D-01 | 0.37000D 02 |
| | | | | | | | |
| -0.11263D 05 | 0.30678D 06 | 0.77519D 04 | 0.48905D 03 | -0.99219D 02 | 0.18061D 01 | -0.67882D-01 | -0.15798D-01 |
| -0.11262D 05 | 0.30678D 06 | 0.77525D 04 | 0.49010D 03 | -0.98990D 02 | 0.14399D 01 | 0.26957D 02 | 0.10952D 05 |
| -0.11262D 05 | 0.22788D 04 | 0.10000D 05 | 0.49010D 03 | -0.99001D 02 | 0.0 | -0.39089D 01 | 0.10971D 05 |
| -0.11263D 05 | 0.22789D 04 | 0.99994D 04 | 0.48905D 03 | -0.99235D 02 | 0.36286D 00 | 0.10147D 03 | 0.99994D 04 |
| 0.14616D 01 | -0.16795D 00 | 0.57817D 00 | 0.10536D 01 | 0.23404D 00 | -0.36286D 00 | 0.0 | 0.0 |
| -0.93753D 00 | 0.68799D 01 | 0.59424D 01 | -0.12500D-01 | 0.91732D-01 | 0.10423D 01 | 0.49901D 03 | 0.0 |
| 0.45719D 00 | 0.45719D 00 | 0.35156D 00 | 0.10142D 03 | 0.10147D 03 | 0.0 | 0.0 | 0.0 |
| -0.25071D 01 | 0.18612D 02 | 0.10887D 00 | 0.0 | 0.29234D-01 | 0.29200D-01 | 0.29264D-01 | 0.38000D 02 |
| | | | | | | | |
| -0.11203D 05 | 0.30676D 06 | 0.77530D 04 | 0.48896D 03 | -0.99297D 02 | 0.19084D 01 | -0.71183D-01 | -0.17762D-01 |
| -0.11201D 05 | 0.30676D 06 | 0.77526D 04 | 0.49009D 03 | -0.99022D 02 | 0.14403D 01 | 0.26958D 02 | 0.10951D 05 |
| -0.11201D 05 | 0.22664D 04 | 0.10000D 05 | 0.49009D 03 | -0.99032D 02 | 0.0 | -0.39131D 01 | 0.10970D 05 |
| -0.11203D 05 | 0.22661D 04 | 0.10000D 05 | 0.48896D 03 | -0.99314D 02 | 0.46400D 00 | 0.10149D 03 | 0.10000D 05 |
| 0.23122D 01 | 0.29935D 00 | -0.39096D 00 | 0.11376D 01 | 0.28230D 00 | -0.46400D 00 | 0.0 | 0.0 |
| -0.19825D 01 | -0.83597D 01 | -0.10342D 02 | -0.26433D-01 | -0.11146D 00 | 0.92056D 00 | 0.49854D 03 | 0.0 |
| 0.45079D 00 | 0.45079D 00 | 0.35156D 00 | 0.10142D 03 | 0.10148D 03 | 0.0 | 0.0 | 0.0 |
| -0.52731D 01 | -0.22128D 02 | 0.23019D 00 | 0.0 | 0.29140D-01 | 0.29106D-01 | 0.29170D-01 | 0.38125D 02 |
| | | | | | | | |
| -0.11141D 05 | 0.30675D 06 | 0.77505D 04 | 0.48897D 03 | -0.99301D 02 | 0.16280D 01 | -0.70084D-01 | -0.16480D-01 |
| -0.11139D 05 | 0.30675D 06 | 0.77528D 04 | 0.49009D 03 | -0.99052D 02 | 0.14408D 01 | 0.26954D 02 | 0.10950D 05 |
| -0.11139D 05 | 0.22540D 04 | 0.10000D 05 | 0.49009D 03 | -0.99063D 02 | 0.0 | -0.39114D 01 | 0.10969D 05 |
| -0.11141D 05 | 0.22540D 04 | 0.99977D 04 | 0.48897D 03 | -0.99314D 02 | 0.18360D 00 | 0.10149D 03 | 0.99977D 04 |
| 0.22141D 01 | 0.14758D-01 | 0.22753D 01 | 0.11213D 01 | 0.25103D 00 | -0.18360D 00 | 0.0 | 0.0 |
| -0.18370D 01 | 0.11637D 01 | -0.67329D 00 | -0.24494D-01 | 0.15517D-01 | 0.79750D 00 | 0.49855D 03 | 0.0 |
| 0.44478D 00 | 0.44478D 00 | 0.35156D 00 | 0.10143D 03 | 0.10148D 03 | 0.0 | 0.0 | 0.0 |
| -0.48594D 01 | 0.33092D 01 | 0.21330D 00 | 0.0 | 0.29046D-01 | 0.29013D-01 | 0.29076D-01 | 0.38250D 02 |
| | | | | | | | |
| -0.11082D 05 | 0.30674D 06 | 0.77491D 04 | 0.48878D 03 | -0.99333D 02 | 0.14579D 01 | -0.77665D-01 | -0.16498D-01 |
| -0.11078D 05 | 0.30674D 06 | 0.77530D 04 | 0.49008D 03 | -0.99083D 02 | 0.14412D 01 | 0.26952D 02 | 0.10946D 05 |
| -0.11078D 05 | 0.22416D 04 | 0.10000D 05 | 0.49008D 03 | -0.99093D 02 | 0.0 | -0.39130D 01 | 0.10965D 05 |
| -0.11082D 05 | 0.22416D 04 | 0.99961D 04 | 0.48878D 03 | -0.99344D 02 | 0.13073D-01 | 0.10149D 03 | 0.99961D 04 |
| 0.40301D 01 | 0.15507D-01 | 0.39171D 01 | 0.13047D 01 | 0.25061D 00 | -0.13073D-01 | 0.0 | 0.0 |
| -0.25407D 01 | -0.56295D 01 | -0.81702D 01 | -0.33876D-01 | -0.75060D-01 | 0.68483D 00 | 0.49877D 03 | 0.0 |
| 0.43913D 00 | 0.43913D 00 | 0.35156D 00 | 0.10143D 03 | 0.10149D 03 | 0.0 | 0.0 | 0.0 |
| -0.66850D 01 | -0.14604D 02 | 0.29490D 00 | 0.0 | 0.28954D-01 | 0.28921D-01 | 0.28983D-01 | 0.38375D 02 |

OUTPUT FORMAT

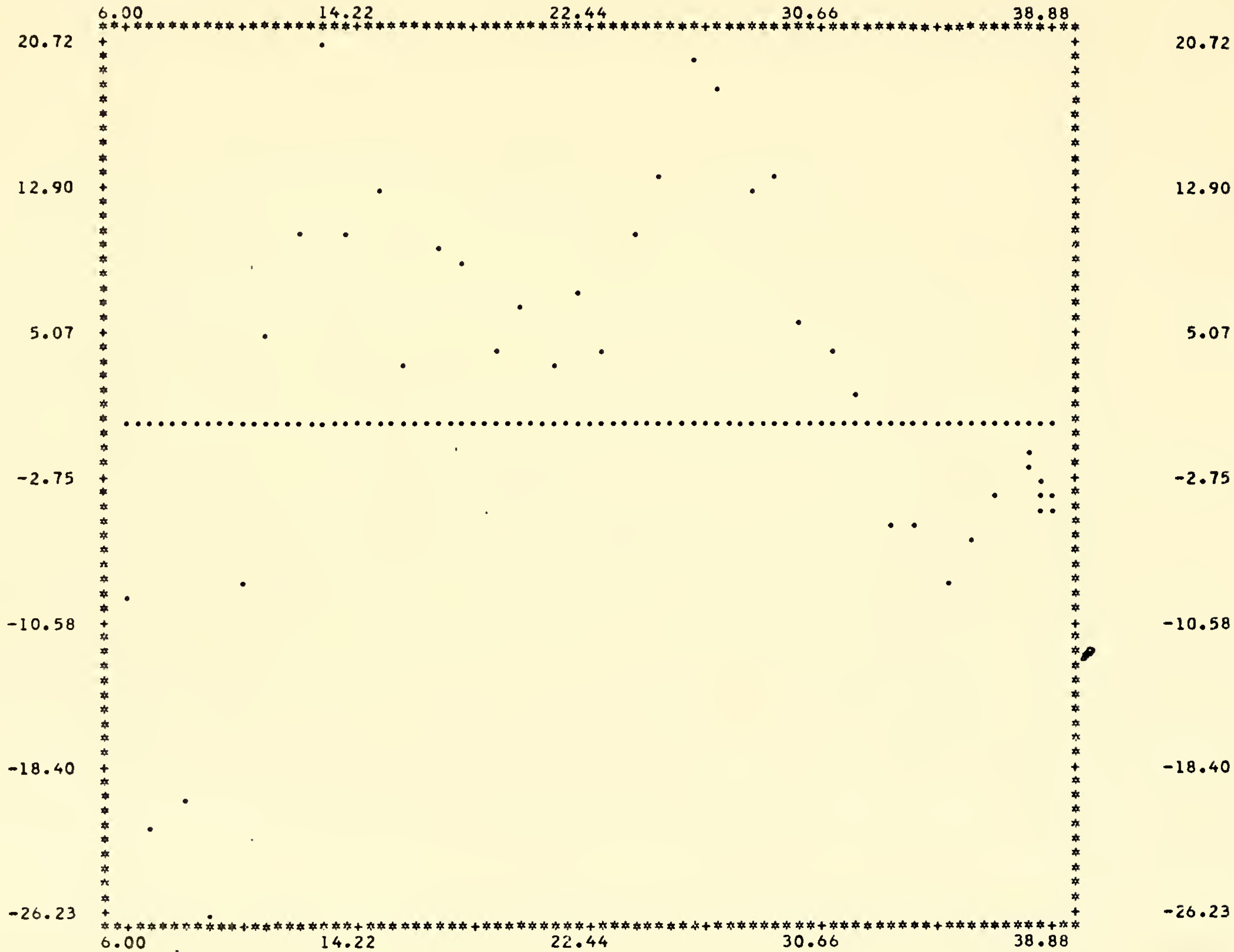
| X1<br>X2<br>X3<br>X5<br>X6<br>PHD1<br>PH<br>XF | Y1<br>Y2<br>Y3<br>Y5<br>Y6<br>PHD2<br>PHI<br>OXE | Z1<br>Z2<br>Z3<br>Z5<br>Z6<br>PHD<br>PHC<br>CTV | XO1<br>XO2<br>XO3<br>XO5<br>XO6<br>HDE<br>PS | YO1<br>YO2<br>YO3<br>YO5<br>YO6<br>HDEDOT<br>PS1<br>G(1,1) | ZO1<br>ZO2<br>ZO3<br>ZO5<br>ZO6<br>TG<br><br>G(4,2) | XDD1<br>TF<br>XGC<br>AA<br>YNP<br>VEH<br><br>G(7,3) | YDD1<br>RA<br>YGC<br>HAT<br><br>THN<br><br>T |
|---|---|---|---|---|---|---|---|
| -0.11020D 05 | 0.30673D 06 | 0.77489D 04 | 0.48889D 03 | -0.99302D 02 | 0.14250D 01 | -0.72600D-01 | -0.13767D-01 |
| -0.11017D 05 | 0.30673D 06 | 0.77532D 04 | 0.49008D 03 | -0.99113D 02 | 0.14416D 01 | 0.26951D 02 | 0.10948D 05 |
| -0.11017D 05 | 0.22292D 04 | 0.10000D 05 | 0.49008D 03 | -0.99123D 02 | 0.0 | -0.39108D 01 | 0.10967D 05 |
| -0.11020D 05 | 0.22298D 04 | 0.99958D 04 | 0.48889D 03 | -0.99313D 02 | -0.19405D-01 | 0.10148D 03 | 0.99958D 04 |
| 0.29498D 01 | -0.55812D 00 | 0.42494D 01 | 0.11850D 01 | 0.18936D 00 | 0.19405D-01 | 0.0 | 0.0 |
| -0.17769D 01 | 0.61109D 01 | 0.43341D 01 | -0.23691D-01 | 0.81479D-01 | 0.55368D 00 | 0.45888D 03 | 0.0 |
| 0.43382D 00 | 0.43382D 00 | 0.35156D 00 | 0.10143D 03 | 0.10148D 03 | 0.0 | 0.0 | 0.0 |
| -0.46489D 01 | 0.16289D 02 | 0.20628D 00 | 0.0 | 0.28862D-01 | 0.28828D-01 | 0.28691D-01 | 0.38500D 02 |
| | | | | | | | |
| -0.10959D 05 | 0.30671D 06 | 0.77495D 04 | 0.48881D 03 | -0.99395D 02 | 0.14704D 01 | -0.75083D-01 | -0.16412D-01 |
| -0.10955D 05 | 0.30671D 06 | 0.77534D 04 | 0.49007D 03 | -0.99143D 02 | 0.14421D 01 | 0.26952D 02 | 0.10946D 05 |
| -0.10955D 05 | 0.22168D 04 | 0.10000D 05 | 0.49007D 03 | -0.99153D 02 | 0.0 | -0.39152D 01 | 0.10966D 05 |
| -0.10959D 05 | 0.22168D 04 | 0.99962D 04 | 0.48881D 03 | -0.99406D 02 | 0.24661D-01 | 0.10150D 03 | 0.99962D 04 |
| 0.37725D 01 | 0.60029D-01 | 0.38463D 01 | 0.12640D 01 | 0.25291D 00 | -0.24661D-01 | 0.0 | 0.0 |
| -0.29941D 01 | -0.97378D 01 | -0.12732D 02 | -0.39921D-01 | -0.12984D 00 | 0.43198D 00 | 0.45881D 03 | 0.0 |
| 0.42884D 00 | 0.42884D 00 | 0.35156D 00 | 0.10144D 03 | 0.10149D 03 | 0.0 | 0.0 | 0.0 |
| -0.77905D 01 | -0.25133D 02 | 0.34755D 00 | 0.0 | 0.28771D-01 | 0.28737D-01 | 0.28300D-01 | 0.38625D 02 |
| | | | | | | | |
| -0.10899D 05 | 0.30670D 06 | 0.77492D 04 | 0.48876D 03 | -0.99388D 02 | 0.14258D 01 | -0.76587D-01 | -0.14765D-01 |
| -0.10894D 05 | 0.30670D 06 | 0.77535D 04 | 0.49006D 03 | -0.99172D 02 | 0.14425D 01 | 0.26951D 02 | 0.10945D 05 |
| -0.10894D 05 | 0.22044D 04 | 0.10000D 05 | 0.49006D 03 | -0.99182D 02 | 0.0 | -0.39150D 01 | 0.10965D 05 |
| -0.10899D 05 | 0.22047D 04 | 0.99957D 04 | 0.48876D 03 | -0.99398D 02 | -0.19837D-01 | 0.10150D 03 | 0.99957D 04 |
| 0.42719D 01 | -0.28857D 00 | 0.42960D 01 | 0.13085D 01 | 0.21588D 00 | 0.19837D-01 | 0.0 | 0.0 |
| -0.29156D 01 | 0.62795D 00 | -0.22876D 01 | -0.38874D-01 | 0.83727D-02 | 0.31030D 00 | 0.49876D 03 | 0.0 |
| 0.42416D 00 | 0.42416D 00 | 0.35156D 00 | 0.10144D 03 | 0.10149D 03 | 0.0 | 0.0 | 0.0 |
| -0.75443D 01 | 0.19701D 01 | 0.33840D 00 | 0.0 | 0.28680D-01 | 0.28646D-01 | 0.28709D-01 | 0.38750D 02 |
| | | | | | | | |
| -0.10836D 05 | 0.30669D 06 | 0.77471D 04 | 0.48884D 03 | -0.99350D 02 | 0.11869D 01 | -0.72413D-01 | -0.11806D-01 |
| -0.10833D 05 | 0.30669D 06 | 0.77537D 04 | 0.49006D 03 | -0.99201D 02 | 0.14429D 01 | 0.26948D 02 | 0.10946D 05 |
| -0.10833D 05 | 0.21920D 04 | 0.10000D 05 | 0.49006D 03 | -0.99211D 02 | 0.0 | -0.39114D 01 | 0.10965D 05 |
| -0.10836D 05 | 0.21930D 04 | 0.99934D 04 | 0.48884D 03 | -0.99357D 02 | -0.25817D 00 | 0.10149D 03 | 0.99934D 04 |
| 0.34921D 01 | -0.96113D 00 | 0.66327D 01 | 0.12208D 01 | 0.14541D 00 | 0.25817D 00 | 0.0 | 0.0 |
| -0.21044D 01 | 0.64695D 01 | 0.43851D 01 | -0.28059D-01 | 0.96526D-01 | 0.18321D 00 | 0.49883D 03 | 0.0 |
| 0.41976D 00 | 0.41976D 00 | 0.35156D 00 | 0.10144D 03 | 0.10149D 03 | 0.0 | 0.0 | 0.0 |
| -0.54144D 01 | 0.17039D 02 | 0.24429D 00 | 0.0 | 0.28589D-01 | 0.28555D-01 | 0.28618D-01 | 0.38875D 02 |
| | | | | | | | |
| -0.10776D 05 | 0.30668D 06 | 0.77479D 04 | 0.48880D 03 | -0.99479D 02 | 0.12593D 01 | -0.73211D-01 | -0.16028D-01 |
| -0.10772D 05 | 0.30668D 06 | 0.77539D 04 | 0.49005D 03 | -0.99230D 02 | 0.14433D 01 | 0.26949D 02 | 0.10946D 05 |
| -0.10772D 05 | 0.21796D 04 | 0.10000D 05 | 0.49005D 03 | -0.99240D 02 | 0.0 | -0.39170D 01 | 0.10965D 05 |
| -0.10776D 05 | 0.21796D 04 | 0.99940D 04 | 0.48880D 03 | -0.99487D 02 | -0.18768D 00 | 0.10150D 03 | 0.99940D 04 |
| 0.38228D 01 | 0.30576D-01 | 0.59856D 01 | 0.12484D 01 | 0.24676D 00 | 0.18768D 00 | 0.0 | 0.0 |
| -0.36572D 01 | -0.12422D 02 | -0.16080D 02 | -0.48763D-01 | -0.16563D 00 | 0.57786D-01 | 0.49883D 03 | 0.0 |
| 0.41563D 00 | 0.41563D 00 | 0.35156D 00 | 0.10145D 03 | 0.10150D 03 | 0.0 | 0.0 | 0.0 |
| -0.93564D 01 | -0.31537D 02 | 0.42453D 00 | 0.0 | 0.28500D-01 | 0.28466D-01 | 0.28529D-01 | 0.39000D 02 |
| | | | | | | | |
| -0.10743D 05 | 0.30667D 06 | 0.77540D 04 | 0.49005D 03 | -0.99243D 02 | 0.14435D 01 | -0.73211D-01 | -0.16028D-01 |
| -0.10743D 05 | 0.30667D 06 | 0.77540D 04 | 0.49005D 03 | -0.99243D 02 | 0.14435D 01 | 0.26960D 02 | 0.10972D 05 |
| -0.10743D 05 | 0.21739D 04 | 0.10000D 05 | 0.49005D 03 | -0.99253D 02 | 0.0 | -0.39025D 01 | 0.10991D 05 |
| -0.10743D 05 | 0.21739D 04 | 0.10000D 05 | 0.49005D 03 | -0.99253D 02 | 0.0 | 0.10145D 03 | 0.10000D 05 |
| 0.0 | 0.11369D-10 | 0.18190D-11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| -0.36572D 01 | -0.12422D 02 | -0.16080D 02 | 0.10005D-01 | 0.10169D 01 | -0.60004D-01 | 0.50000D 03 | 0.0 |
| 0.41380D 00 | 0.41563D 00 | 0.35156D 00 | 0.10145D 03 | 0.10150D 03 | 0.0 | 0.0 | 0.0 |
| 0.19136D 01 | -0.31537D 02 | 0.42453D 00 | 0.0 | 0.28500D-01 | 0.28466D-01 | 0.28529D-01 | 0.39058D 02 |

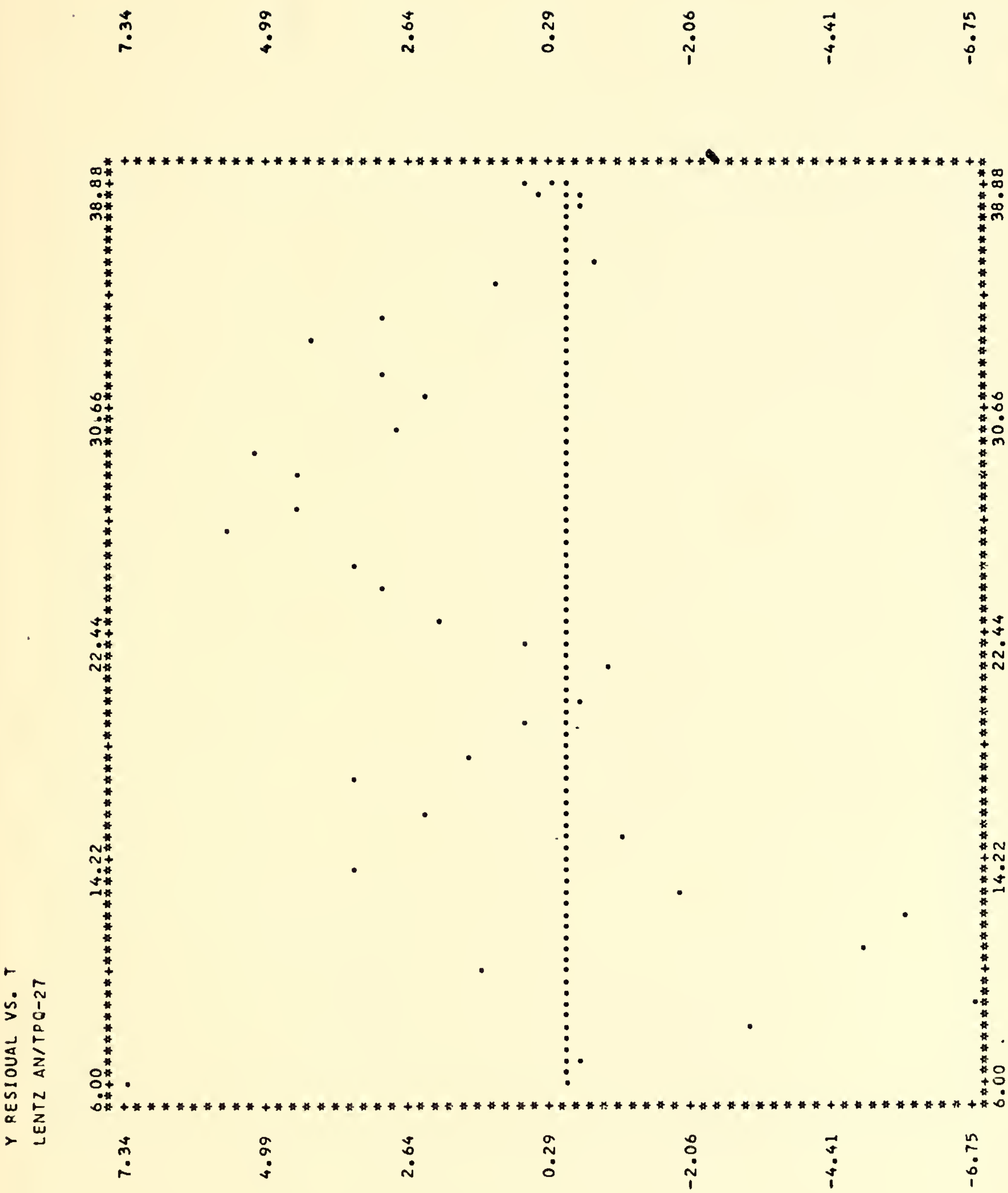
XI = 2.97849D 01     YI = -4.08013D 00     RI = 3.00631D 01

AVG X RESIDUAL = 13.5116     AVG Y RESIDUAL = 4.4865     AVG Z RESIDUAL = 10.6162

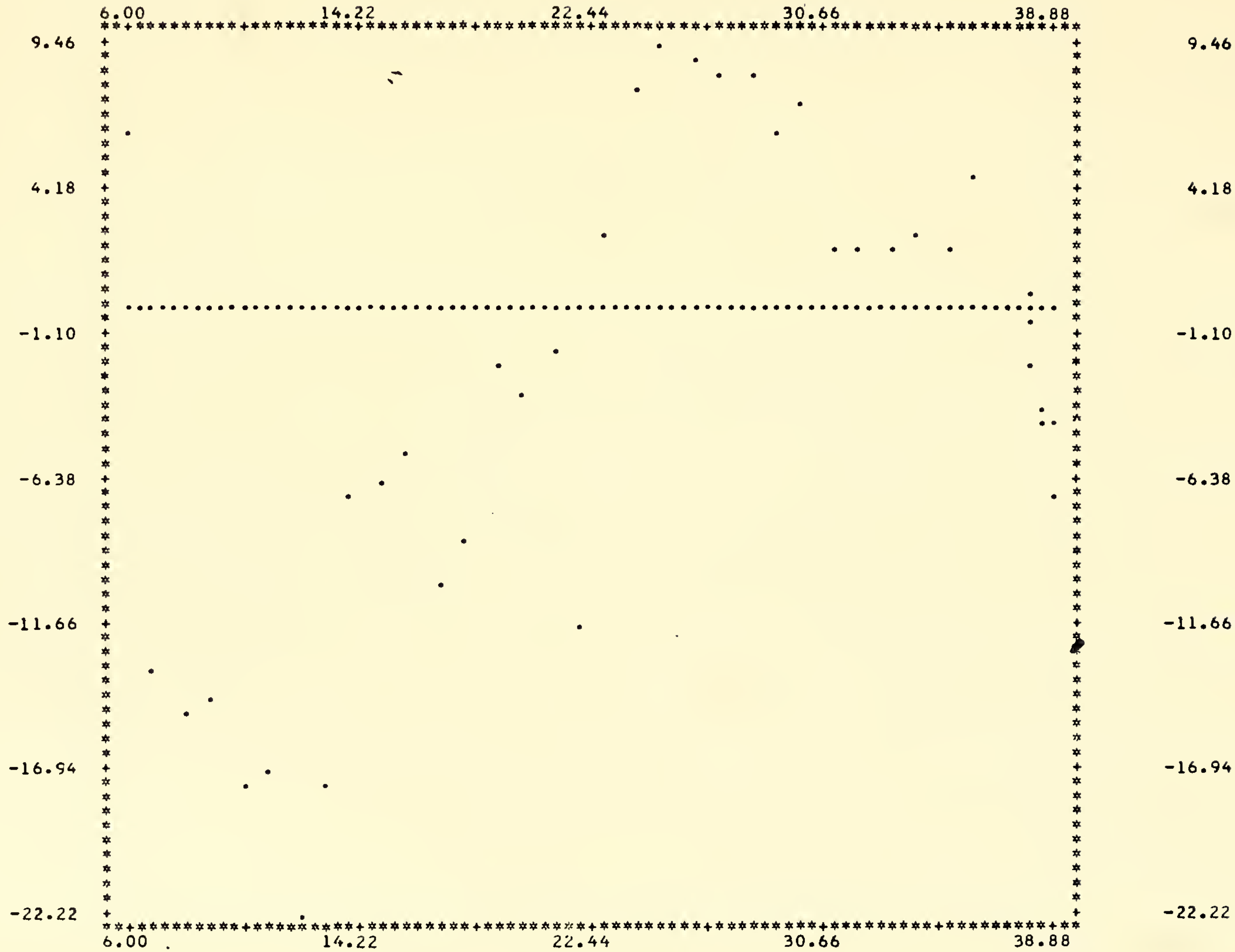
AVG RADIAL RESIDUAL = 17.7594

X RESIDUAL VS. T
LENTZ AN/TPQ-27

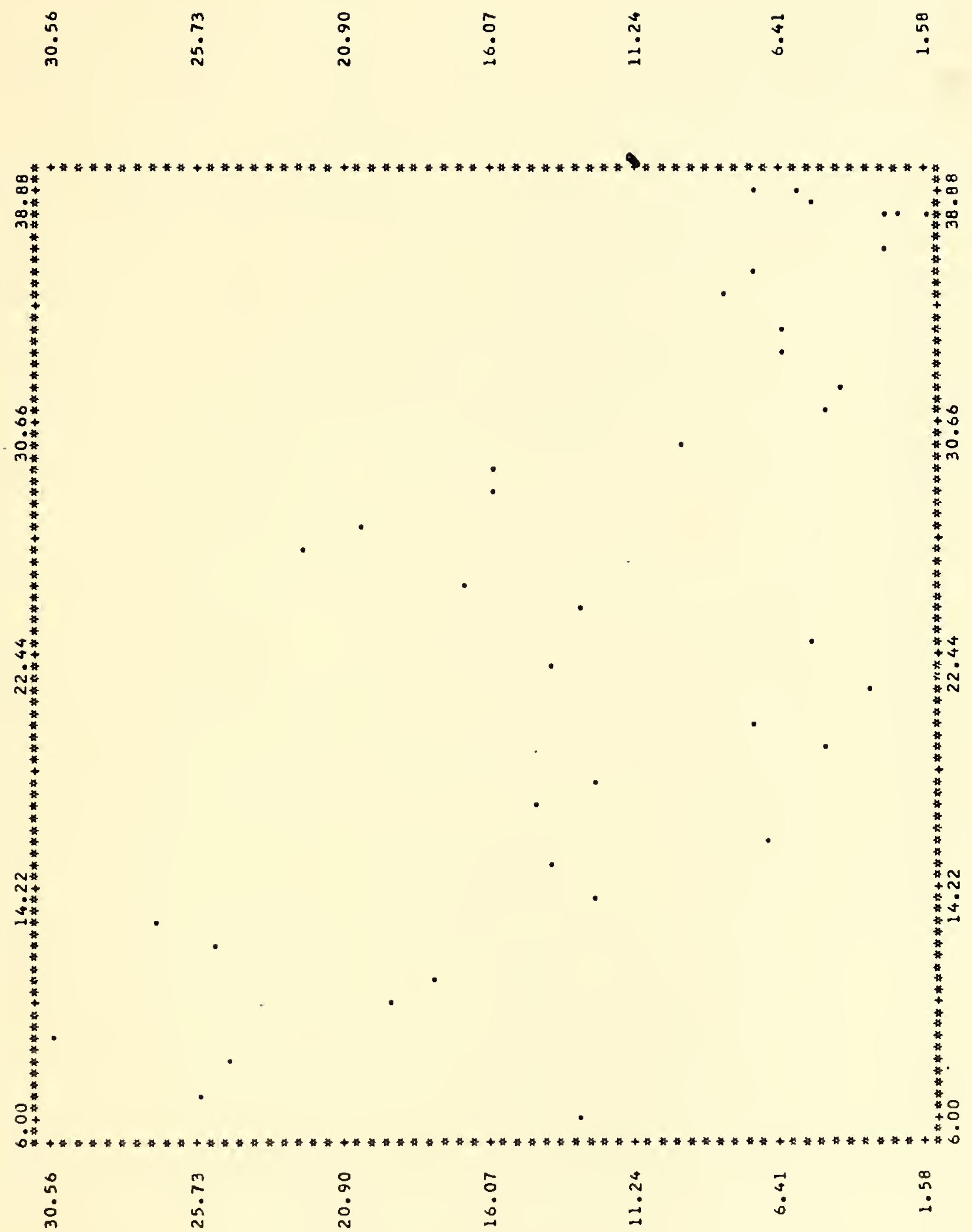



Y RESIDUAL VS. T
LENTZ AN/TPQ-27
7.34
4.99
2.64
0.29
-2.06
-4.41
-6.75
6.00
14.22
22.44
30.66
38.88

Z RESIDUAL VS. T
LENTZ AN/TPQ-27

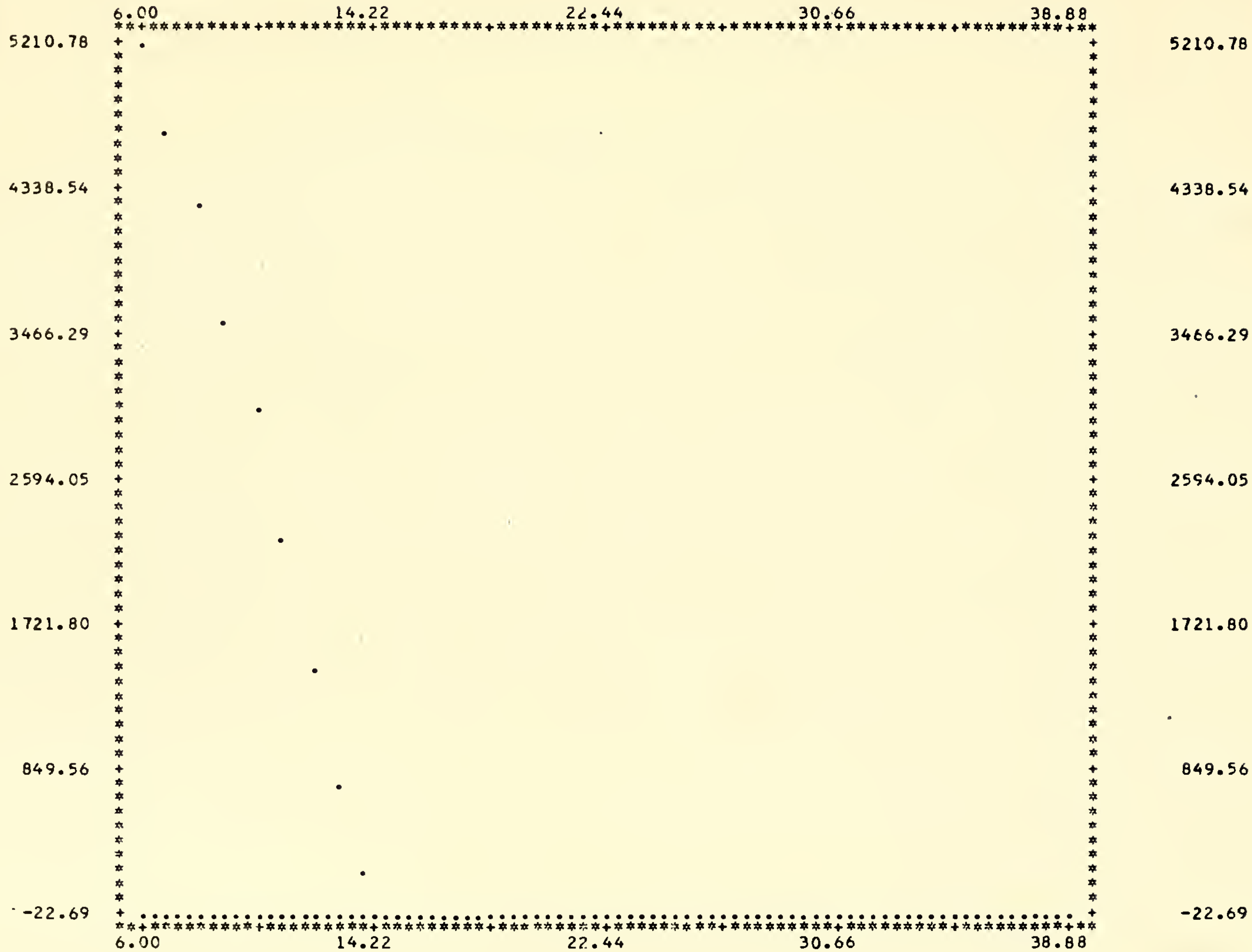


RADIAL RESIDUAL VS. T
LENTZ AN/TPQ-27



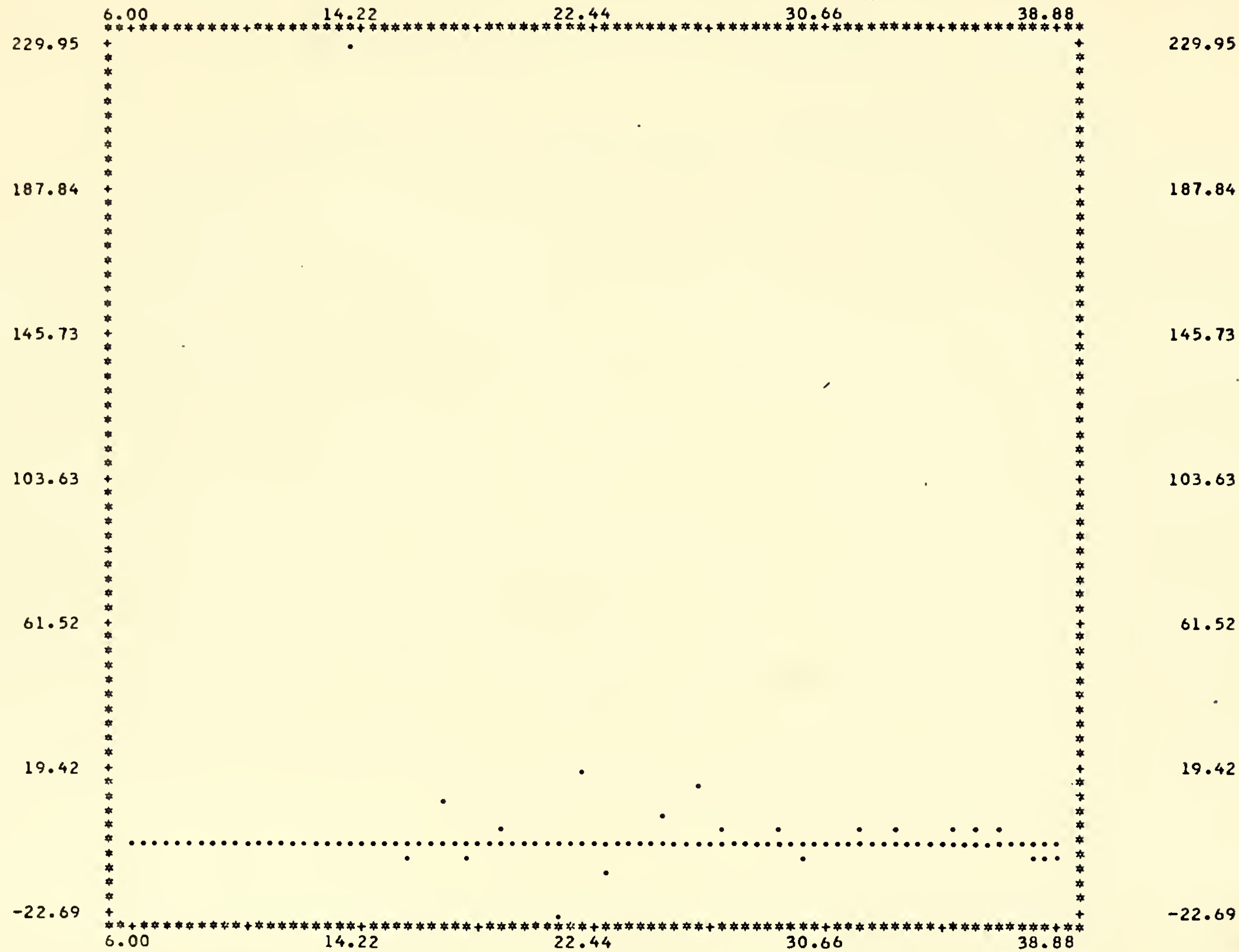
LATERAL ERROR (XE) VS. T

LENTZ AN/TPQ-27

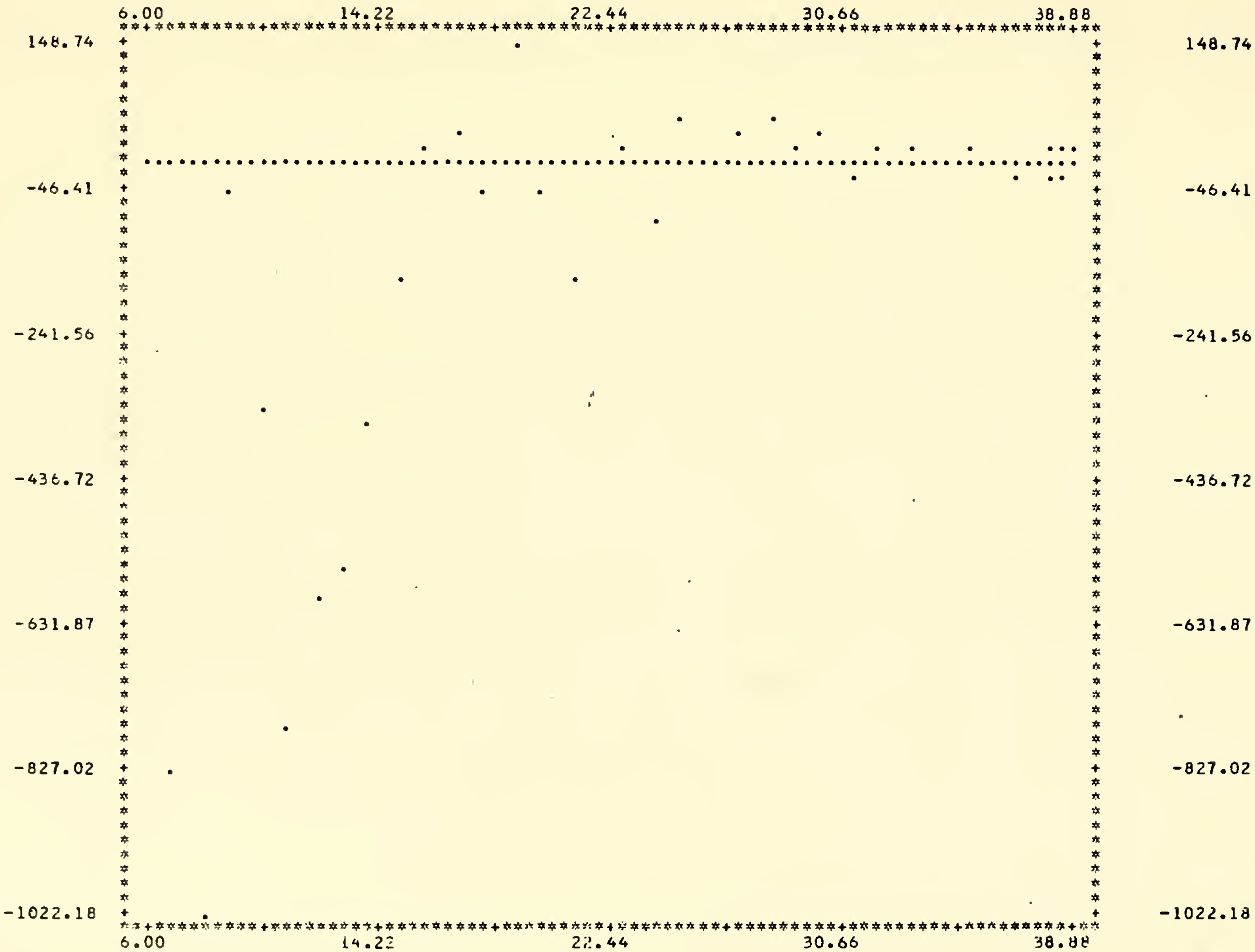


LATERAL ERROR (EXPANDED SCALE) VS. T

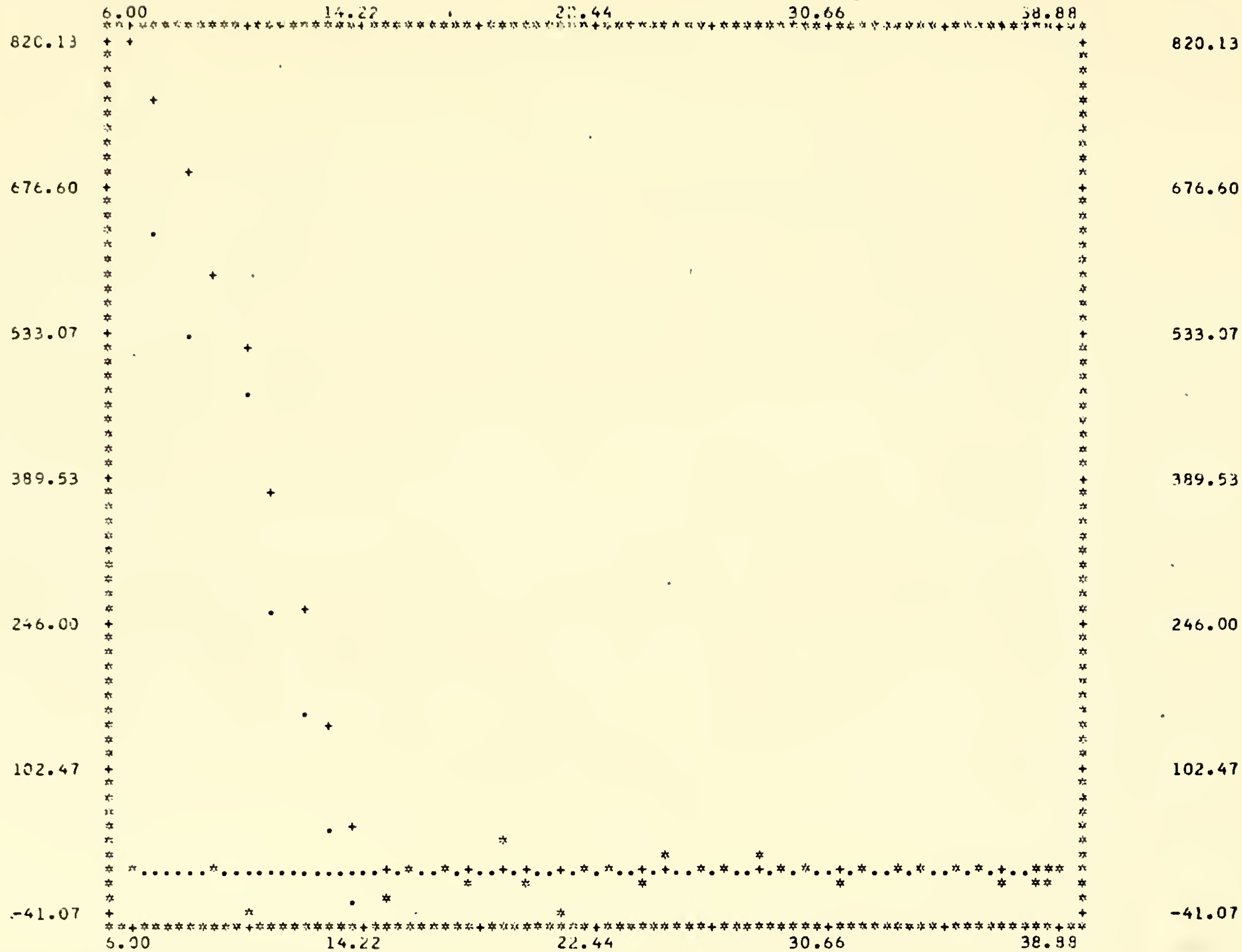
LENTZ AN/TPQ-27



LATERAL ERROR RATE (DXE) VS. T
LENTZ AN/TPQ-27

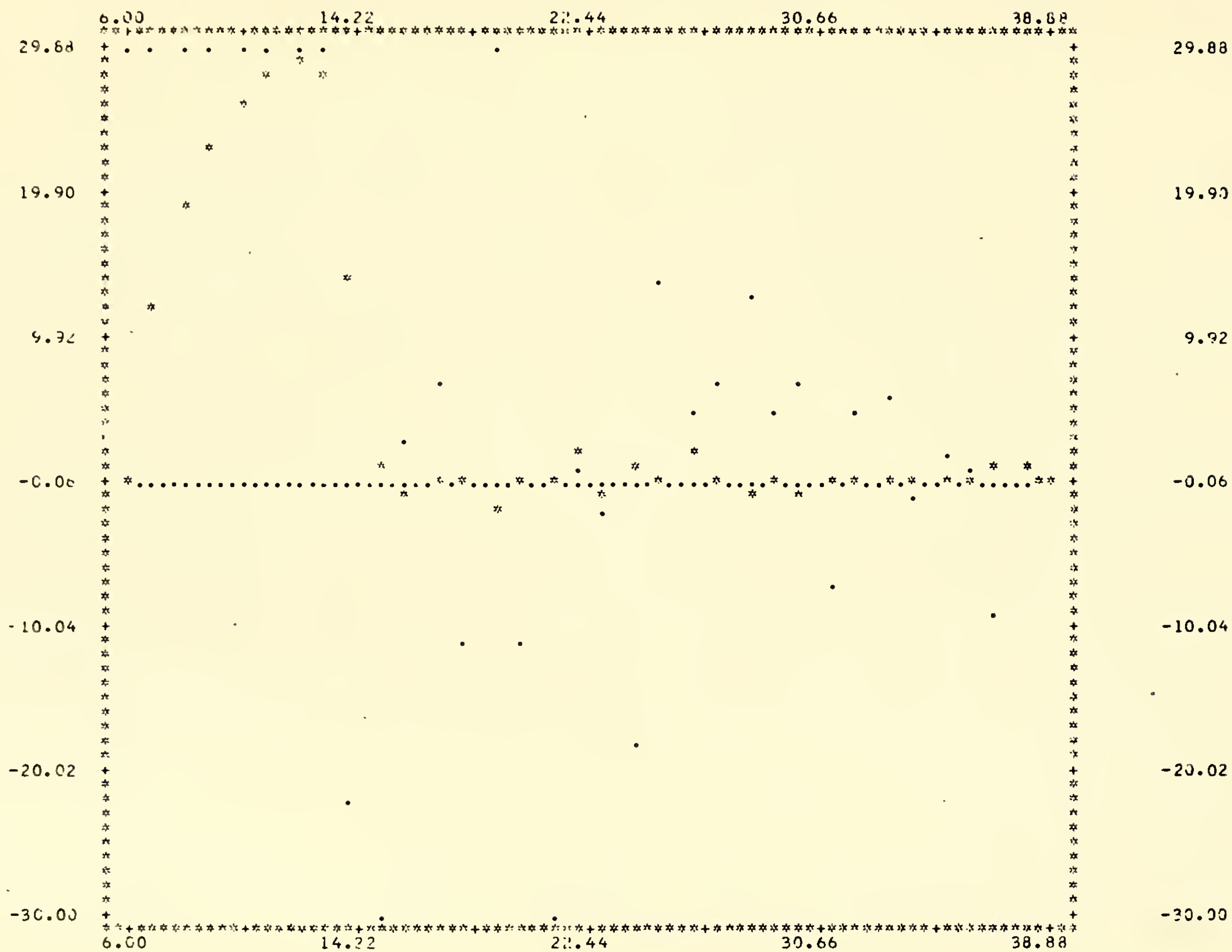


PHO,PHD1, AND PHD2 VS. T
LENTZ AN/TPQ-27

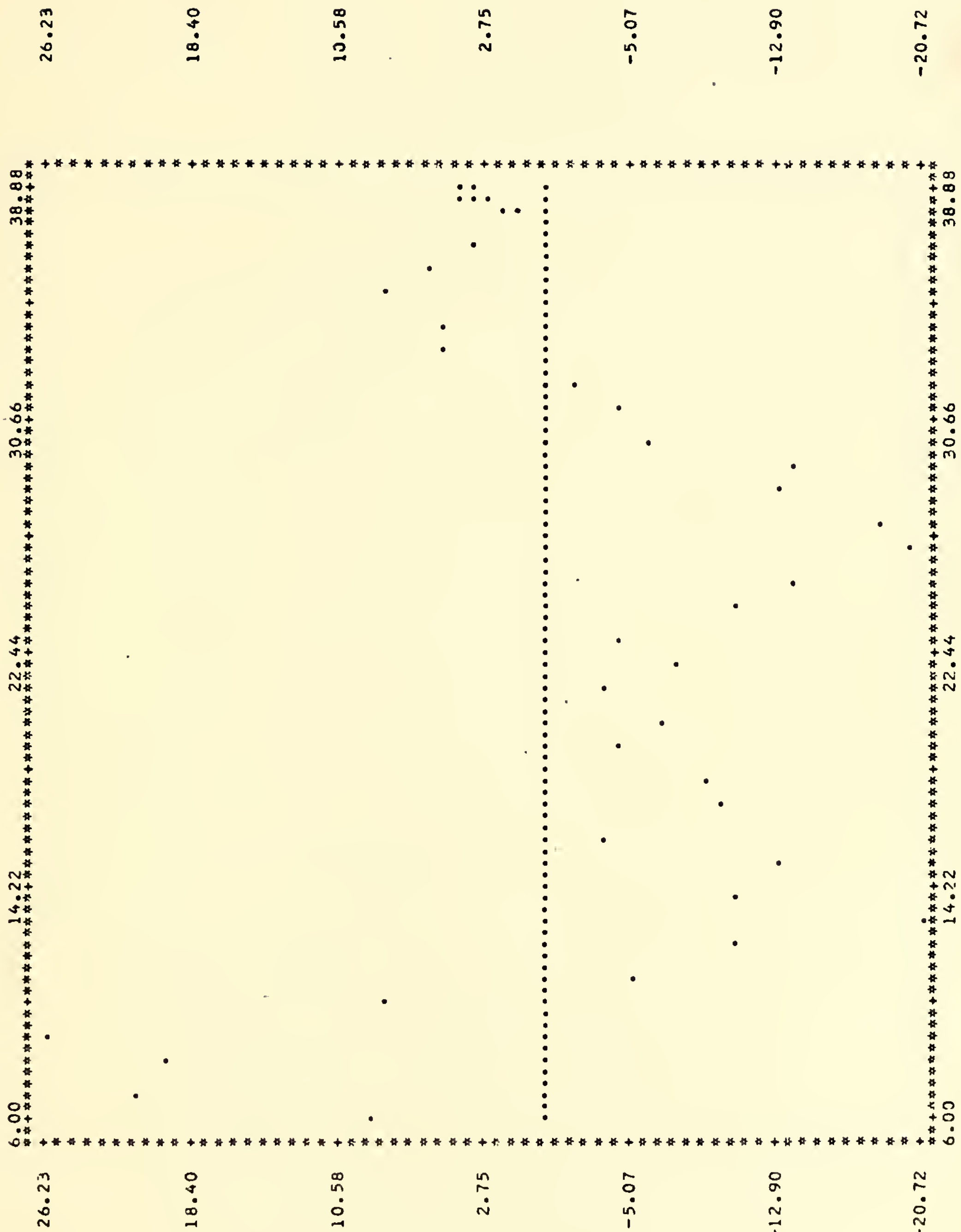


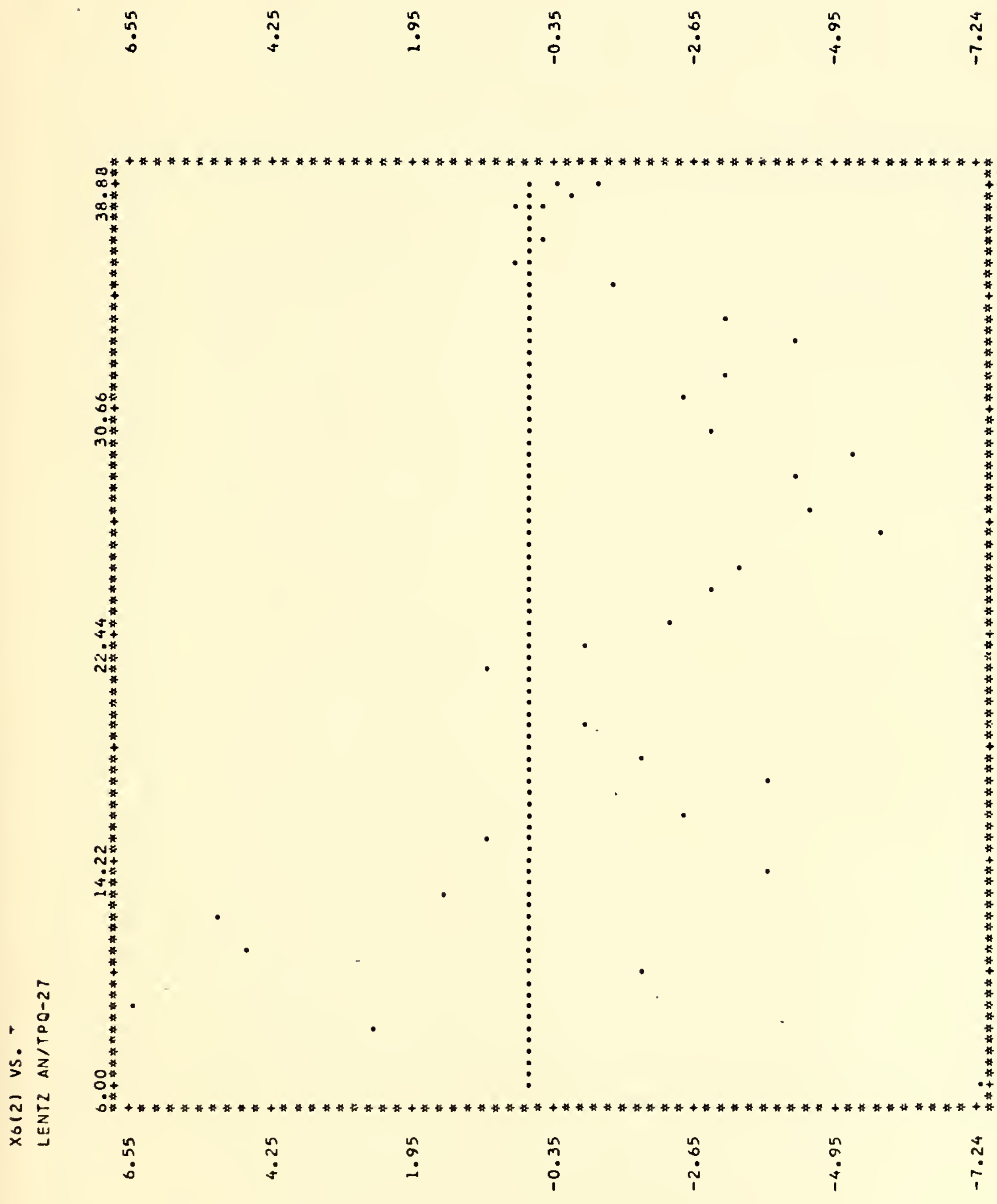
ROLL ANGLE(COMMAND,ACTUAL,BEST) VS. T

LENTZ AN/TPQ-27

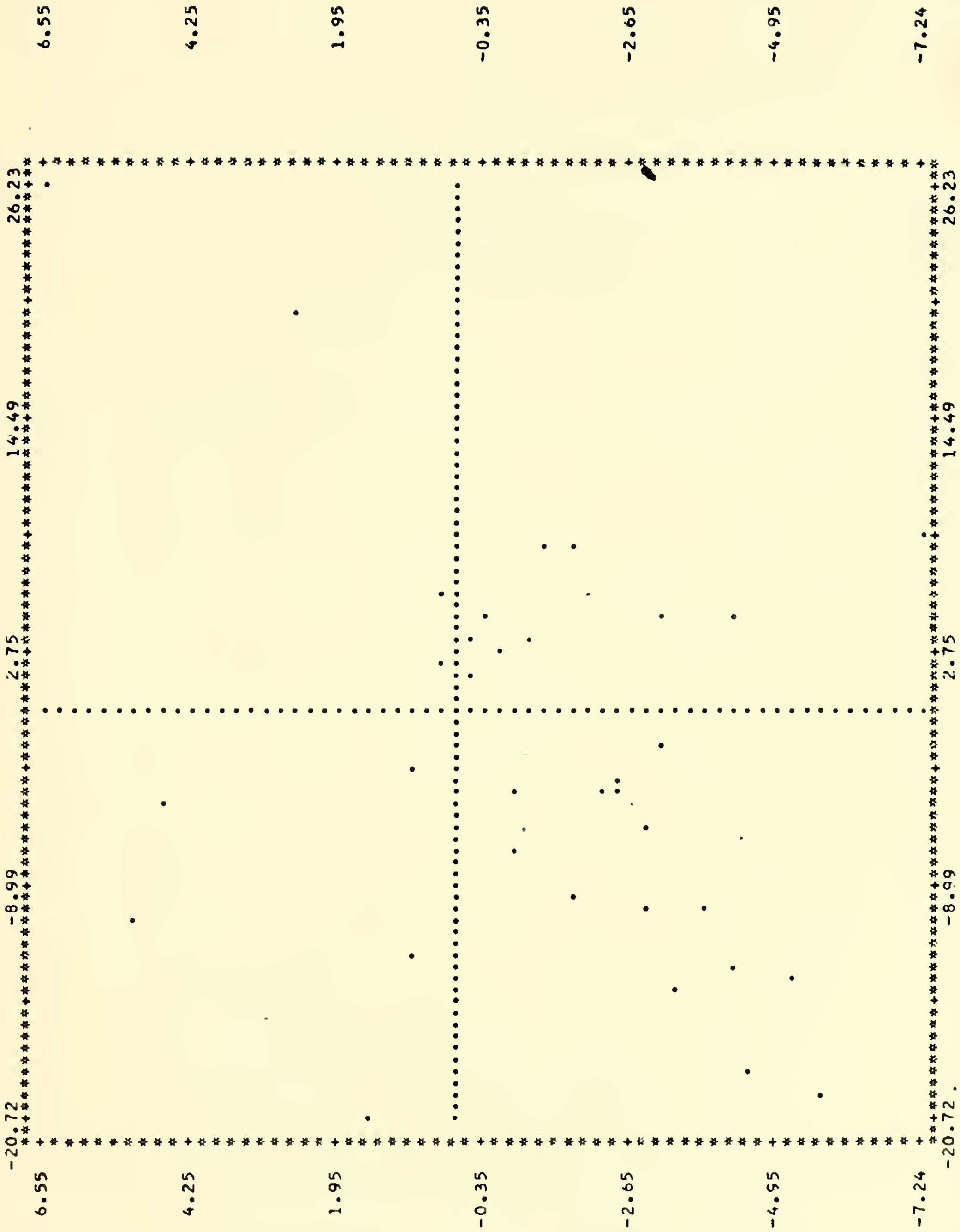


X6(I) VS. T
LENTZ AN/TPQ-27



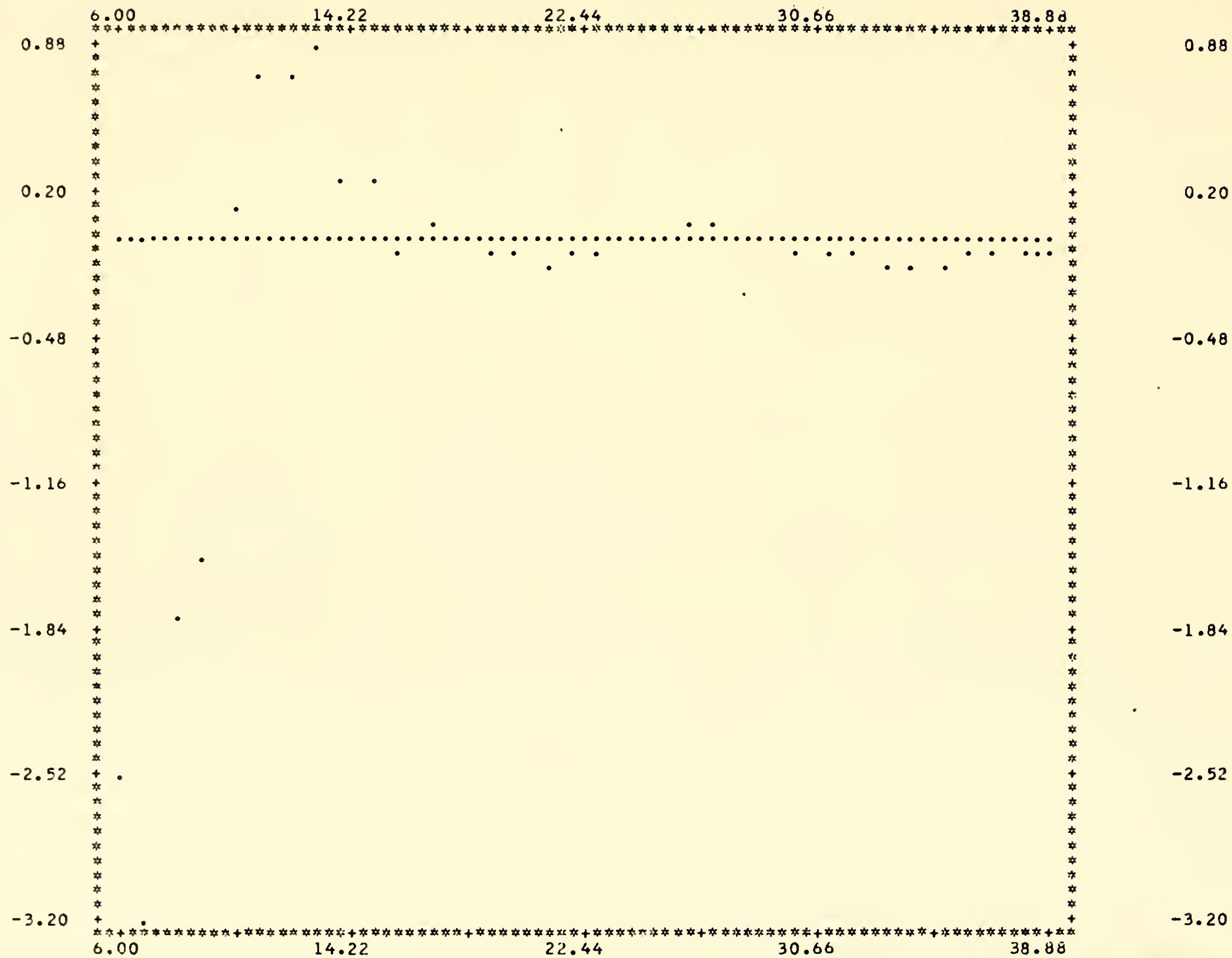

X6(2) VS. T
LENTZ AN/TPQ-27
6.55
4.25
1.95
-0.35
-2.65
-4.95
-7.24
6.00
14.22
22.44
30.66
38.88

X6(2) VS. X6(1)
LENTZ AN/TPQ-27

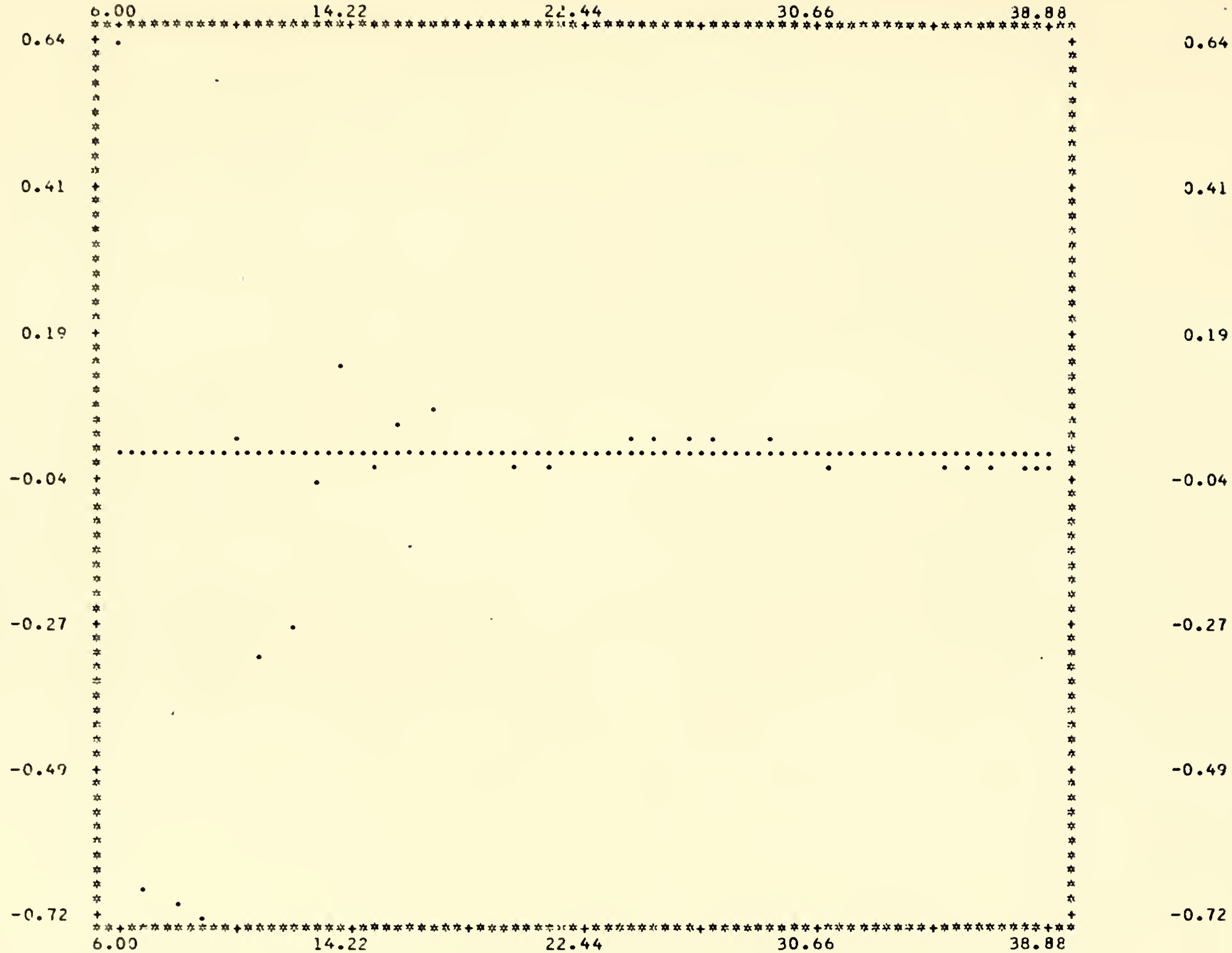


X ACCELERATION ESTIMATE(XDD1(1)) VS. T

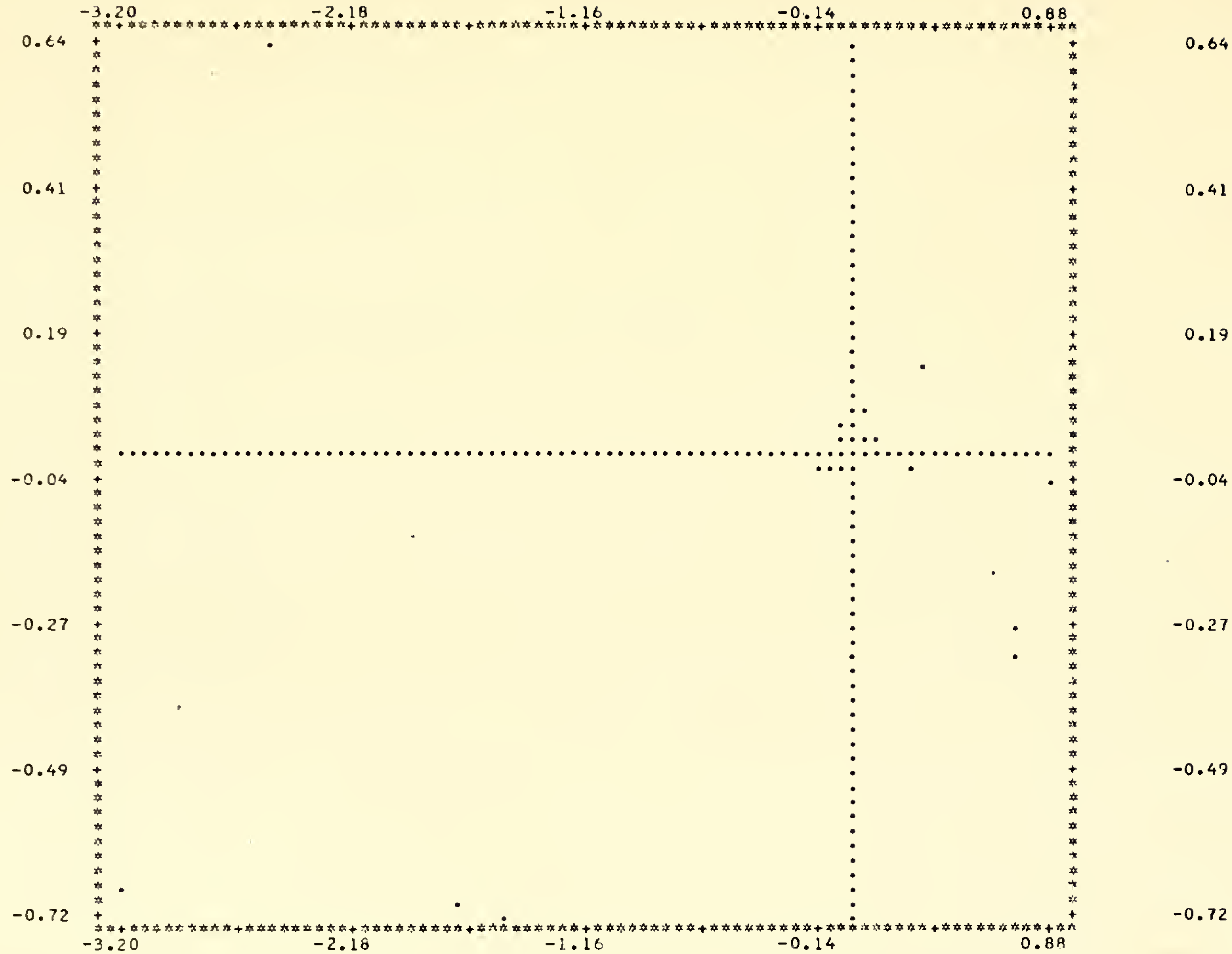
LENTZ AN/TPQ-27



Y ACCELERATION ESTIMATE(XOD1(2)) VS. T
LENTZ AN/TPQ-27



X ACCELERATION VS. Y ACCELERATION
LENTZ AN/TPQ-27



```
                         AN/TPQ-27 SIMULATION
              COARSE GUIDANCE MODE WITH KALMAN FILTERING

INITIAL CONDITIONS :

   TRUE WIND =  50.00 FT/SEC AT  45.00 DEGREES
   TRUE WIND COMPONENTS =  35.36 35.36
   ESTIMATED WIND =  50.00 FT/SEC AT  45.00 DEGREES
   ESTIMATED WIND COMPONENTS =  35.36 35.36

   RADAR DATA

     MEASUREMENT SIGMAS(R(FT.),AZ(DEG),EL(DEG)) =      9.000000 02    4.000000-01    4.000000-01
     MEASUREMENT BIASES(          "          ) =      0.0            0.0            0.0
     INITIAL VELOCITY MEASUREMENT VALUES =            0.0            0.0            0.0
     RANDOM FORCING ASSUMPTION VALUES (SIGW) =        0.0            0.0            0.0
     SAMPLING INTERVAL FOR RADAR (DTRAD) =   6.000

   AIRCRAFT DATA

     TRUE INITIAL DISPLACEMENT FROM STARTING POINT (NM) =    2.000   2.000   0.0
     TRUE INITIAL GROUND VELOCITY =    550.00 FT/SEC AT  45.00 DEGREES
     TRUE INITIAL GROUND VELOCITY COMPONENTS =   388.91  388.91
     TRUE INITIAL AIR VELOCITY =   500.00 FT/SEC AT  45.00 DEGREES
     ROLL RESPONSE PARAMETER (TB) = 3.300

   TRACK DATA

     NUMBER OF LEGS (NLEGS) =   3
     POSITION OF FIRST LEG =   50.000 NM AT  45.00 DEGREES
     COMPONENTS OF START POINT =   35.355  35.355

   CONTROL DATA

     CONTROL INTERVAL =  1.000
     MAXIMUM BANK ANGLE =   30.00

     G1 =    4.000
     G2 =    4.000

     MIN HEADING ERROR ANGLE FOR COMMAND CORRECTION =    5.000

LEG NUMBER 1

     LEG START POINT (X,Y) =    35.3553   35.3553
     LEG END POINT (X,Y) =      40.3553   44.0156

     LEG LENGTH (NM) =        10.00
     LEG AZIMUTH (DEG) =      30.00

     DESIRED GROUND SPEED (FT/SEC) =  548.13
     DESIRED AIR HEADING (DEG) =  28.52

     AVG RANGE OF LEG FROM RADAR (NM) =        54.84
     AVG AZIMUTH OF LEG FROM RADAR (DEG) =     43.65

     TLEG = 110.852
```

| T | PHC | PHI | TLEG1 | TTURN1 | TQ21 | TT21 | HTG | HEG | HTA | HEA | ETFUE | FEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 0.0 | 45.00 | 0.0 | 0.7321 | 0.4312 | 0.0 | 0.0 |
| 1.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 0.0 | 45.00 | 0.0 | 0.7555 | 0.4333 | 0.0 | 0.0 |
| 2.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 0.0 | 45.00 | 0.0 | 0.7789 | 0.4355 | 0.0 | 0.0 |
| 3.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 0.0 | 45.00 | 0.0 | 0.8023 | 0.4376 | 0.0 | 0.0 |
| 4.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 0.0 | 45.00 | 0.0 | 0.8258 | 0.4397 | 0.0 | 0.0 |
| 5.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 0.0 | 45.00 | 0.0 | 0.8492 | 0.4419 | 0.0 | 0.0 |
| 6.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 37.80 | 45.00 | 36.92 | 0.8726 | 0.4926 | 0.0 | 0.0 |
| 7.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 37.80 | 45.00 | 36.92 | 0.8960 | 0.5028 | 0.0 | 0.0 |
| 8.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 37.80 | 45.00 | 36.92 | 0.9195 | 0.5131 | 0.0 | 0.0 |
| 9.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 37.80 | 45.00 | 36.92 | 0.9429 | 0.5233 | 0.0 | 0.0 |
| 10.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 37.80 | 45.00 | 36.92 | 0.9663 | 0.5335 | 0.0 | 0.0 |
| 11.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 37.80 | 45.00 | 36.92 | 0.9898 | 0.5438 | 0.0 | 0.0 |
| 12.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 45.00 | 37.66 | 45.00 | 36.71 | 1.0132 | 0.5467 | 0.0 | 0.0 |
| 13.00 | 0.0 | 0.0 | 100.9142 | 22.2506 | 14.8530 | 18.1395 | 45.00 | 37.66 | 45.00 | 36.71 | 1.0366 | 0.5563 | 0.0 | 0.0 |
| 14.00 | -29.8828 | -7.8121 | 99.5156 | 22.4009 | 14.9419 | 18.2288 | 44.76 | 37.36 | 44.74 | 36.37 | 1.0595 | 0.5657 | -50.9282 | -50.9282 |
| 15.00 | -29.8828 | -13.5819 | 97.5015 | 22.8006 | 15.1769 | 18.4647 | 44.13 | 36.53 | 44.04 | 35.46 | 1.0825 | 0.5743 | -50.2869 | 0.6413 |
| 16.00 | -29.8828 | -17.8433 | 95.1112 | 23.3903 | 15.5198 | 18.8087 | 43.20 | 35.38 | 43.02 | 34.13 | 1.1039 | 0.5818 | -47.6342 | 2.6527 |
| 17.00 | -29.8828 | -20.9907 | 92.5293 | 24.1282 | 15.9473 | 19.2326 | 42.06 | 33.93 | 41.77 | 32.50 | 1.1238 | 0.5876 | -43.4711 | 4.1631 |
| 18.00 | -29.8828 | -23.3153 | 71.7919 | 15.9463 | 13.7697 | 17.0509 | 40.76 | 41.24 | 40.34 | 40.89 | 1.1417 | 0.8513 | -38.1657 | 5.3054 |
| 19.00 | -29.8828 | -25.0322 | 69.4074 | 16.3974 | 14.1439 | 17.4271 | 39.34 | 39.92 | 38.78 | 39.45 | 1.1575 | 0.8691 | -79.8191 | -41.6535 |
| 20.00 | -29.8828 | -26.3003 | 67.0591 | 16.8825 | 14.5409 | 17.8260 | 37.84 | 38.51 | 37.12 | 37.91 | 1.1710 | 0.8646 | -75.3560 | 3.9631 |
| 21.00 | -29.8828 | -27.2368 | 64.7734 | 17.3954 | 14.9549 | 18.2417 | 36.27 | 37.05 | 35.40 | 36.32 | 1.1821 | 0.8973 | -71.5236 | 4.3324 |
| 22.00 | -29.8828 | -27.9286 | 62.5659 | 17.9318 | 15.3813 | 18.6698 | 34.65 | 35.54 | 33.62 | 34.67 | 1.1907 | 0.9094 | -66.8956 | 4.6280 |
| 23.00 | -29.8823 | -28.4394 | 60.4443 | 18.4886 | 15.8169 | 19.1068 | 33.00 | 34.00 | 31.81 | 32.99 | 1.1968 | 0.9164 | -62.0270 | 4.8686 |
| 24.00 | -29.8828 | -28.8168 | 60.8346 | 20.1649 | 16.5708 | 19.8628 | 31.32 | 31.39 | 29.97 | 30.08 | 1.2002 | 0.8835 | -56.9569 | 5.0701 |
| 25.00 | -29.8828 | -29.0955 | 58.8568 | 20.8197 | 17.0392 | 20.3323 | 29.62 | 29.73 | 28.10 | 28.27 | 1.2009 | 0.8844 | -45.2054 | 11.7516 |
| 26.00 | -29.8828 | -29.3013 | 56.9715 | 21.4929 | 17.5115 | 20.8055 | 27.91 | 28.06 | 26.22 | 26.44 | 1.1990 | 0.8826 | -39.3605 | 5.8449 |
| 27.00 | -27.1875 | -26.7487 | 55.1841 | 22.1753 | 17.9807 | 21.2755 | 26.20 | 26.41 | 24.36 | 24.63 | 1.1944 | 0.8781 | -33.3610 | 5.9995 |
| 28.00 | -21.0938 | -26.7475 | 53.5118 | 22.8402 | 18.4236 | 21.7241 | 24.58 | 24.82 | 22.53 | 22.90 | 1.1871 | 0.8710 | -27.2995 | 6.0615 |
| 29.00 | -15.4688 | -23.7990 | 51.9636 | 23.4569 | 18.8361 | 22.1321 | 23.09 | 23.38 | 20.95 | 21.33 | 1.1774 | 0.8615 | -21.4292 | 5.8703 |
| 30.00 | 0.0 | -17.5774 | 51.5945 | 22.5681 | 18.3492 | 21.6445 | 21.88 | 25.09 | 19.63 | 23.21 | 1.1656 | 0.9711 | -16.0244 | 5.4048 |
| 31.00 | -29.8828 | -20.7943 | 50.1836 | 23.0290 | 18.6581 | 21.9539 | 20.75 | 22.99 | 18.39 | 22.02 | 1.1521 | 0.9622 | -29.3795 | -13.3550 |
| 32.00 | -21.6797 | -21.0258 | 48.7759 | 23.5369 | 18.9935 | 22.2896 | 19.51 | 22.81 | 17.05 | 20.72 | 1.1367 | 0.9515 | -25.5689 | 3.8106 |
| 33.00 | -16.8750 | -19.9407 | 47.4133 | 24.0413 | 19.3214 | 22.6179 | 18.31 | 21.64 | 15.73 | 19.46 | 1.1195 | 0.9389 | -21.3068 | 4.2620 |
| 34.00 | 0.0 | -14.7277 | 46.1350 | 24.4717 | 19.5972 | 22.8940 | 17.29 | 20.66 | 14.62 | 18.39 | 1.1005 | 0.9246 | -17.0651 | 4.2418 |

| T | PHC | PHI | TLEG1 | TTURN1 | TG21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35.00 | 0.0 | -10.8775 | 44.9454 | 24.7934 | 19.8010 | 23.0979 | 16.54 | 19.94 | 13.81 | 17.61 | 1.0802 | 0.9039 | -13.4821 | 3.5829 |
| 36.00 | 0.0 | -8.0339 | 43.4188 | 25.7809 | 20.3700 | 23.6694 | 15.98 | 17.92 | 13.20 | 15.40 | 1.0590 | 0.8204 | -10.8596 | 2.6225 |
| 37.00 | 0.0 | -5.9326 | 42.3371 | 25.9640 | 20.4835 | 23.7810 | 15.57 | 17.52 | 12.76 | 14.97 | 1.0370 | 0.8007 | 1.2609 | 12.1205 |
| 38.00 | 0.0 | -4.3825 | 41.2798 | 26.1000 | 20.5658 | 23.8634 | 15.27 | 17.23 | 12.43 | 14.65 | 1.0145 | 0.7805 | 2.8958 | 1.6349 |
| 39.00 | 0.0 | -3.2368 | 40.2393 | 26.2007 | 20.6266 | 23.9243 | 15.05 | 17.01 | 12.13 | 14.42 | 0.9916 | 0.7599 | 4.1518 | 1.2560 |
| 40.00 | 0.0 | -2.3906 | 39.2106 | 26.2754 | 20.6715 | 23.9692 | 14.83 | 16.85 | 12.00 | 14.24 | 0.9684 | 0.7390 | 5.1308 | 0.9790 |
| 41.00 | 0.0 | -1.7656 | 38.1902 | 26.3306 | 20.7047 | 24.0024 | 14.76 | 16.74 | 11.87 | 14.12 | 0.9451 | 0.7179 | 5.9083 | 0.7775 |
| 42.00 | 0.0 | -1.3041 | 41.6014 | 27.3408 | 20.5276 | 23.8252 | 14.67 | 17.51 | 11.77 | 14.80 | 0.9215 | 0.7513 | 6.5402 | 0.6319 |
| 43.00 | 0.0 | -0.9632 | 40.5884 | 27.3744 | 20.5469 | 23.8445 | 14.60 | 17.45 | 11.70 | 14.73 | 0.8979 | 0.7724 | -0.3351 | -6.8752 |
| 44.00 | 0.0 | -0.7114 | 39.5790 | 27.3995 | 20.5611 | 23.8587 | 14.55 | 17.39 | 11.65 | 14.67 | 0.8741 | 0.7533 | -0.0676 | 0.2674 |
| 45.00 | 0.0 | -0.5254 | 38.5723 | 27.4177 | 20.5716 | 23.8692 | 14.52 | 17.36 | 11.61 | 14.63 | 0.8503 | 0.7342 | 0.1344 | 0.2020 |
| 46.00 | 0.0 | -0.3880 | 37.5675 | 27.4313 | 20.5793 | 23.8769 | 14.49 | 17.33 | 11.58 | 14.60 | 0.8264 | 0.7151 | 0.2884 | 0.1540 |
| 47.00 | 0.0 | -0.2866 | 36.5640 | 27.4413 | 20.5850 | 23.8827 | 14.47 | 17.31 | 11.56 | 14.58 | 0.8026 | 0.6959 | 0.2884 | 0.1540 |
| 48.00 | 0.0 | -0.2117 | 37.8147 | 28.0422 | 20.5317 | 23.8293 | 14.45 | 17.58 | 11.54 | 14.78 | 0.7786 | 0.7190 | 0.2884 | 0.1540 |
| 49.00 | 0.0 | -0.1563 | 36.8127 | 28.0481 | 20.5349 | 23.8325 | 14.44 | 17.57 | 11.53 | 14.77 | 0.7547 | 0.7007 | 0.2884 | 0.1540 |
| 50.00 | 0.0 | -0.1155 | 35.8112 | 28.0523 | 20.5373 | 23.8349 | 14.44 | 17.56 | 11.52 | 14.76 | 0.7308 | 0.6824 | 0.2884 | 0.1540 |
| 51.00 | 0.0 | -0.0853 | 34.8102 | 28.0555 | 20.5390 | 23.8366 | 14.43 | 17.55 | 11.51 | 14.76 | 0.7068 | 0.6641 | 0.2884 | 0.1540 |
| 52.00 | 0.0 | -0.0630 | 33.8095 | 28.0578 | 20.5402 | 23.8379 | 14.43 | 17.55 | 11.51 | 14.75 | 0.6828 | 0.6458 | 0.2884 | 0.1540 |
| 53.00 | 0.0 | -0.0465 | 32.8090 | 28.0596 | 20.5413 | 23.8389 | 14.42 | 17.54 | 11.51 | 14.75 | 0.6589 | 0.6275 | 0.2884 | 0.1540 |
| 54.00 | 0.0 | -0.0344 | 29.4487 | 28.5495 | 21.1103 | 24.4033 | 14.42 | 15.47 | 11.50 | 12.55 | 0.6349 | 0.4501 | 0.2884 | 0.1540 |
| 55.00 | 0.0 | -0.0254 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 14.42 | 15.47 | 11.50 | 12.55 | 0.6109 | 0.4284 | 0.2884 | 0.1540 |

STARTING TURN T = 56.00 TINTRN = 0.0

| T | PHC | PHI | TLEG1 | TTURN1 | TG21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56.00 | 30.0000 | 7.8240 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 14.66 | 15.72 | 11.77 | 12.82 | 0.5871 | 0.4068 | 0.2884 | 0.1540 |
| 57.00 | 30.0000 | 13.6213 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 15.30 | 16.38 | 12.46 | 13.54 | 0.5639 | 0.3858 | 0.2884 | 0.1540 |
| 58.00 | 30.0000 | 17.9031 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 16.24 | 17.35 | 13.49 | 14.60 | 0.5419 | 0.3561 | 0.2884 | 0.1540 |
| 59.00 | 30.0000 | 21.0655 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 17.40 | 18.54 | 14.74 | 15.90 | 0.5215 | 0.3479 | 0.2884 | 0.1540 |
| 60.00 | 30.0000 | 23.4012 | 28.4485 | 28.5504 | 21.1109 | 24.4088 | 18.72 | 19.90 | 16.18 | 17.38 | 0.5029 | 0.3316 | 0.2884 | 0.1540 |
| 61.00 | 30.0000 | 25.1263 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 20.15 | 21.37 | 17.74 | 19.00 | 0.4865 | 0.3174 | 0.2884 | 0.1540 |
| 62.00 | 30.0000 | 26.4004 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 21.67 | 22.94 | 19.40 | 20.71 | 0.4723 | 0.3055 | 0.2884 | 0.1540 |
| 63.00 | 30.0000 | 27.3414 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 23.26 | 24.57 | 21.13 | 22.50 | 0.4605 | 0.2950 | 0.2884 | 0.1540 |
| 64.00 | 30.0000 | 28.0364 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 24.89 | 26.25 | 22.92 | 24.34 | 0.4512 | 0.2890 | 0.2884 | 0.1540 |
| 65.00 | 30.0000 | 28.5497 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 26.55 | 27.96 | 24.74 | 26.23 | 0.4445 | 0.2846 | 0.2884 | 0.1540 |
| 66.00 | 30.0000 | 28.9289 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 28.24 | 29.70 | 26.59 | 28.14 | 0.4404 | 0.2828 | 0.2884 | 0.1540 |
| 67.00 | 30.0000 | 29.2089 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 29.95 | 31.46 | 28.46 | 30.07 | 0.4390 | 0.2837 | 0.2884 | 0.1540 |
| 68.00 | 30.0000 | 29.4157 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 31.67 | 33.23 | 30.35 | 32.02 | 0.4402 | 0.2873 | 0.2884 | 0.1540 |

| T | PHC | PHI | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHD1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 69.00 | 30.0000 | 29.5685 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 33.40 | 35.01 | 32.24 | 33.98 | 0.4442 | 0.2936 | 0.2884 | 0.1540 |
| 70.00 | 30.0000 | 29.6813 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 35.13 | 36.80 | 34.15 | 35.95 | 0.4509 | 0.3026 | 0.2884 | 0.1540 |
| 71.00 | 30.0000 | 29.7646 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 36.87 | 38.59 | 36.06 | 37.93 | 0.4604 | 0.3144 | 0.2884 | 0.1540 |
| 72.00 | 30.0000 | 29.8261 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 38.62 | 40.39 | 37.98 | 39.91 | 0.4726 | 0.3288 | 0.2884 | 0.1540 |
| 73.00 | 30.0000 | 29.8716 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 40.36 | 42.19 | 39.90 | 41.90 | 0.4875 | 0.3460 | 0.2884 | 0.1540 |
| 74.00 | 30.0000 | 29.9052 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 42.11 | 43.99 | 41.82 | 43.88 | 0.5051 | 0.3659 | 0.2884 | 0.1540 |
| 75.00 | 30.0000 | 29.9300 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 43.86 | 45.79 | 43.75 | 45.87 | 0.5255 | 0.3885 | 0.2884 | 0.1540 |
| 76.00 | 30.0000 | 29.9483 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 45.61 | 47.60 | 45.68 | 47.86 | 0.5485 | 0.4137 | 0.2884 | 0.1540 |
| 77.00 | 30.0000 | 29.9618 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 47.37 | 49.40 | 47.60 | 49.86 | 0.5742 | 0.4416 | 0.2884 | 0.1540 |
| 78.00 | 30.0000 | 29.9718 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 49.12 | 51.21 | 49.53 | 51.85 | 0.6025 | 0.4721 | 0.2884 | 0.1540 |
| 79.00 | 30.0000 | 29.9792 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 50.87 | 53.02 | 51.46 | 53.84 | [illegible] | 0.5051 | 0.2884 | 0.1540 |
| 80.00 | 30.0000 | 29.9846 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 52.63 | 54.83 | [illegible] | [illegible] | [illegible] | 0.5407 | 0.2884 | 0.1540 |
| 81.00 | 30.0000 | 29.9886 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 54.39 | 56.64 | 55.32 | 57.83 | 0.4938 | 0.5344 | 0.2884 | 0.1540 |
| 82.00 | 30.0000 | 29.9916 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 55.14 | 58.45 | 57.25 | 59.82 | 0.4423 | 0.4874 | 0.2884 | 0.1540 |
| 83.00 | 30.0000 | 29.9938 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | [illegible] | 60.26 | 59.18 | 61.82 | 0.3932 | 0.4428 | 0.2884 | 0.1540 |
| 84.00 | 30.0000 | 29.9954 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | [illegible] | 62.07 | 61.11 | 63.81 | 0.3464 | 0.4006 | 0.2884 | 0.1540 |
| 85.00 | 30.0000 | 29.9966 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 61.42 | 63.89 | 63.04 | 65.81 | 0.3020 | 0.3609 | 0.2884 | 0.1540 |
| 86.00 | 30.0000 | 29.9975 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 63.18 | 65.71 | 64.97 | 67.30 | 0.2601 | 0.3237 | 0.2884 | 0.1540 |
| 87.00 | 30.0000 | 29.9982 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 64.95 | 67.53 | 66.90 | 69.80 | 0.2209 | 0.2891 | 0.2884 | 0.1540 |
| 88.00 | 30.0000 | 29.9986 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 66.71 | 69.35 | 68.83 | 71.79 | 0.1839 | 0.2570 | 0.2884 | 0.1540 |
| 89.00 | 30.0000 | 29.9990 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 68.48 | 71.17 | 70.76 | 73.79 | 0.1497 | 0.2277 | 0.2884 | 0.1540 |
| 90.00 | 30.0000 | 29.9993 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 70.25 | 73.00 | 72.69 | 75.78 | 0.1181 | 0.2010 | 0.2884 | 0.1540 |
| 91.00 | 30.0000 | 29.9995 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 72.02 | 74.83 | 74.62 | 77.78 | 0.0891 | 0.1769 | 0.2884 | 0.1540 |
| 92.00 | 30.0000 | 29.9996 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 73.79 | 76.66 | 76.55 | 79.77 | 0.0628 | 0.1556 | 0.2884 | 0.1540 |
| 93.00 | 30.0000 | 29.9997 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 75.57 | 78.50 | 78.48 | 81.77 | 0.0392 | 0.1370 | 0.2884 | 0.1540 |
| 94.00 | 30.0000 | 29.9998 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 77.35 | 80.34 | 80.41 | 83.76 | 0.0183 | 0.1212 | 0.2884 | 0.1540 |
| 95.00 | 30.0000 | 29.9998 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 79.13 | 82.13 | 82.34 | 85.76 | 0.0002 | 0.1081 | 0.2884 | 0.1540 |
| 96.00 | 30.0000 | 29.9999 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 80.91 | 84.02 | 84.27 | 87.75 | -0.0152 | 0.0977 | 0.2884 | 0.1540 |
| 97.00 | 30.0000 | 29.9999 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 82.70 | 85.87 | 86.20 | 89.75 | -0.0279 | 0.0902 | 0.2884 | 0.1540 |
| 98.00 | 30.0000 | 29.9999 | 28.4485 | 28.5504 | 21.1108 | 24.4088 | 84.49 | 87.72 | 88.13 | 91.74 | -0.0378 | 0.0854 | 0.2884 | 0.1540 |

TURN ENDING T = 99.00 TINTRN = 43.00

LEG NUMBER 2

LEG START POINT (X,Y) = 40.3553 44.0156
LEG END POINT (X,Y) = 50.3553 44.0156

LEG LENGTH (NM) = 10.00
LEG AZIMUTH (DEG) = 90.00

DESIRED GROUND SPEED (FT/SEC) = 534.10
DESIRED AIR HEADING (DEG) = 94.05

AVG RANGE OF LEG FROM RADAR (NM) = 63.20
AVG AZIMUTH OF LEG FROM RADAR (DEG) = 45.86

TLEG = 113.762

| T | PHC | PHI | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHD1 | PHD2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99.00 | 0.0 | 22.1573 | 95.8523 | 21.7079 | 16.8215 | 20.1140 | 86.04 | 89.32 | 89.80 | 93.46 | -0.0450 | 0.0833 | 0.2884 | 0.1540 |
| 100.00 | 0.0 | 16.3648 | 93.8596 | 22.2024 | 17.1507 | 20.4440 | 87.18 | 90.51 | 91.03 | 94.73 | -0.0502 | 0.0832 | 0.2884 | 0.1540 |
| 101.00 | 0.0 | 12.0867 | 92.1754 | 22.5729 | 17.3938 | 20.6876 | 88.03 | 91.38 | 91.94 | 95.67 | -0.0538 | 0.0846 | 0.2884 | 0.1540 |
| 102.00 | 0.0 | 8.9269 | 90.6970 | 22.8496 | 17.5734 | 20.8675 | 88.65 | 92.03 | 92.61 | 96.37 | -0.0564 | 0.0872 | 0.2884 | 0.1540 |
| 103.00 | 0.0 | 6.5932 | 89.3589 | 23.0556 | 17.7061 | 21.0004 | 89.11 | 92.51 | 93.11 | 96.88 | -0.0581 | 0.0906 | 0.2884 | 0.1540 |
| 104.00 | 0.0 | 4.8696 | 88.1180 | 23.2086 | 17.8040 | 21.0985 | 89.46 | 92.86 | 93.47 | 97.26 | -0.0592 | 0.0945 | 0.2884 | 0.1540 |
| | TURN COMPLETE | T = 105.00 | | TINTRN = | 49.00 | | | | | | | | | |
| 105.00 | 0.0 | 3.5966 | 86.9452 | 23.3222 | 17.8764 | 21.1710 | 89.71 | 93.12 | 93.74 | 97.54 | -0.0598 | 0.0990 | 0.2884 | 0.1540 |
| 106.00 | 0.0 | 2.6563 | 85.8208 | 23.4064 | 17.9298 | 21.2245 | 89.89 | 93.32 | 93.94 | 97.74 | -0.0601 | 0.1038 | -15.4525 | -15.7409 |
| 107.00 | 0.0 | 1.9619 | 84.7309 | 23.4687 | 17.9693 | 21.2641 | 90.03 | 93.46 | 94.09 | 97.89 | -0.0601 | 0.1088 | -16.4021 | -0.9495 |
| 108.00 | 0.0 | 1.4490 | 82.7192 | 22.0452 | 17.3560 | 20.6496 | 90.13 | 91.35 | 94.20 | 95.53 | -0.0600 | -0.0322 | -17.1614 | -0.7593 |
| 109.00 | 0.0 | 1.0702 | 81.6678 | 22.0764 | 17.3769 | 20.6706 | 90.21 | 91.43 | 94.28 | 95.61 | -0.0597 | -0.0301 | -4.3890 | 12.7724 |
| 110.00 | 0.0 | 0.7904 | 80.6306 | 22.0995 | 17.3924 | 20.6862 | 90.26 | 91.48 | 94.34 | 95.67 | -0.0594 | -0.0279 | -4.7468 | -0.3578 |
| 111.00 | 0.0 | 0.5838 | 79.6034 | 22.1166 | 17.4038 | 20.6976 | 90.30 | 91.52 | 94.38 | 95.71 | -0.0589 | -0.0256 | -5.0300 | -0.2832 |
| 112.00 | 0.0 | 0.4312 | 78.5837 | 22.1293 | 17.4123 | 20.7061 | 90.34 | 91.55 | 94.41 | 95.74 | -0.0584 | -0.0233 | -5.2586 | -0.2286 |
| 113.00 | 0.0 | 0.3185 | 77.5693 | 22.1386 | 17.4185 | 20.7123 | 90.36 | 91.58 | 94.44 | 95.77 | -0.0579 | -0.0209 | -5.4475 | -0.1888 |
| 114.00 | 0.0 | 0.2352 | 78.2271 | 21.8555 | 17.1711 | 20.4644 | 90.37 | 90.66 | 94.46 | 94.81 | -0.0574 | -0.0938 | -5.6074 | -0.1600 |
| 115.00 | 0.0 | 0.1737 | 77.2189 | 21.8606 | 17.1745 | 20.4678 | 90.39 | 90.68 | 94.47 | 94.83 | -0.0568 | -0.0928 | 0.5077 | 6.1152 |
| 116.00 | 0.0 | 0.1283 | 76.2129 | 21.8643 | 17.1770 | 20.4703 | 90.40 | 90.69 | 94.43 | 94.84 | -0.0562 | -0.0917 | 0.4647 | -0.0431 |
| 117.00 | 0.0 | 0.0948 | 75.2086 | 21.8671 | 17.1789 | 20.4722 | 90.40 | 90.69 | 94.49 | 94.84 | -0.0556 | -0.0907 | 0.4341 | -0.0306 |
| 118.00 | 0.0 | 0.0700 | 74.2054 | 21.8691 | 17.1803 | 20.4736 | 90.41 | 90.70 | 94.49 | 94.85 | -0.0549 | -0.0896 | 0.4128 | -0.0213 |
| 119.00 | 0.0 | 0.0517 | 73.2031 | 21.8706 | 17.1813 | 20.4746 | 90.41 | 90.70 | 94.49 | 94.85 | -0.0543 | -0.0886 | 0.3983 | -0.0144 |
| 120.00 | 0.0 | 0.0382 | 73.9070 | 21.6439 | 16.9602 | 20.2531 | 90.41 | 89.88 | 94.50 | 94.00 | -0.0537 | -0.1599 | 0.3890 | -0.0093 |
| 121.00 | 0.0 | 0.0282 | 72.9057 | 21.6447 | 16.9608 | 20.2536 | 90.42 | 89.88 | 94.50 | 94.00 | -0.0530 | -0.1600 | 6.2915 | 5.9025 |
| 122.00 | 0.0 | 0.0208 | 71.9048 | 21.6453 | 16.9612 | 20.2541 | 90.42 | 89.89 | 94.50 | 94.00 | -0.0524 | -0.1602 | 6.3710 | 0.0795 |
| 123.00 | 0.0 | 0.0154 | 70.9041 | 21.6458 | 16.9615 | 20.2544 | 90.42 | 89.89 | 94.50 | 94.00 | -0.0518 | -0.1604 | 6.4550 | 0.0840 |

| T | PHC | PHI | TLEG1 | TTURN1 | TC21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHD1 | PHD2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 124.00 | 0.0 | 0.0114 | 69.9036 | 21.6461 | 16.9617 | 20.2546 | 90.42 | 89.89 | 94.50 | 94.00 | -0.0511 | -0.1606 | 6.5431 | 0.0881 |
| 125.00 | 0.0 | 0.0084 | 68.9032 | 21.6464 | 16.9619 | 20.2548 | 90.42 | 89.89 | 94.50 | 94.00 | -0.0505 | -0.1607 | 6.6349 | 0.0919 |
| 126.00 | 0.0 | 0.0062 | 67.6369 | 21.3346 | 16.8272 | 20.1198 | 90.42 | 89.43 | 94.50 | 93.48 | -0.0498 | -0.2014 | 6.7304 | 0.0955 |
| 127.00 | 0.0 | 0.0046 | 66.6367 | 21.3347 | 16.8273 | 20.1199 | 90.42 | 89.43 | 94.50 | 93.49 | -0.0492 | -0.2023 | 10.3196 | 3.5891 |
| 128.00 | 0.0 | 0.0034 | 65.6365 | 21.3348 | 16.8274 | 20.1200 | 90.42 | 89.43 | 94.50 | 93.49 | -0.0486 | -0.2031 | 10.4771 | 0.1575 |
| 129.00 | 0.0 | 0.0025 | 64.6364 | 21.3349 | 16.8274 | 20.1200 | 90.42 | 89.43 | 94.50 | 93.49 | -0.0479 | -0.2040 | 10.6399 | 0.1628 |
| 130.00 | 0.0 | 0.0018 | 63.6363 | 21.3349 | 16.8275 | 20.1200 | 90.42 | 89.43 | 94.50 | 93.49 | -0.0473 | -0.2049 | 10.8061 | 0.1682 |
| 131.00 | 0.0 | 0.0014 | 62.6363 | 21.3350 | 16.8275 | 20.1201 | 90.42 | 89.43 | 94.51 | 93.49 | -0.0466 | -0.2057 | 10.9820 | 0.1739 |
| 132.00 | 0.0 | 0.0010 | 62.8422 | 21.2942 | 16.7298 | 20.0222 | 90.42 | 89.06 | 94.51 | 93.11 | -0.0460 | -0.2455 | 11.1617 | 0.1797 |
| 133.00 | 0.0 | 0.0007 | 61.8422 | 21.2942 | 16.7299 | 20.0222 | 90.42 | 89.06 | 94.51 | 93.11 | -0.0453 | -0.2469 | 14.4836 | 3.3220 |
| 134.00 | 0.0 | 0.0005 | 60.8422 | 21.2942 | 16.7299 | 20.0222 | 90.42 | 89.06 | 94.51 | 93.11 | -0.0447 | -0.2484 | 14.7260 | 0.2424 |
| 135.00 | 0.0 | 0.0004 | 59.8422 | 21.2942 | 16.7299 | 20.0222 | 90.42 | 89.06 | 94.51 | 93.11 | -0.0440 | -0.2498 | 14.9767 | 0.2507 |
| 136.00 | 0.0 | 0.0003 | 58.8421 | 21.2942 | 16.7299 | 20.0222 | 90.42 | 89.06 | 94.51 | 93.11 | -0.0434 | -0.2512 | 15.2361 | 0.2594 |
| 137.00 | 0.0 | 0.0002 | 57.8421 | 21.2942 | 16.7299 | 20.0222 | 90.42 | 89.06 | 94.51 | 93.11 | -0.0427 | -0.2526 | 15.5046 | 0.2685 |
| 138.00 | 0.0 | 0.0002 | 53.4136 | 21.3131 | 16.9656 | 20.2585 | 90.42 | 89.98 | 94.51 | 94.02 | -0.0421 | -0.1495 | 15.7828 | 0.2782 |
| 139.00 | 0.0 | 0.0001 | 52.4136 | 21.3131 | 16.9656 | 20.2585 | 90.42 | 89.98 | 94.51 | 94.02 | -0.0415 | -0.1495 | 7.4997 | -8.2831 |
| 140.00 | 0.0 | 0.0001 | 51.4136 | 21.3131 | 16.9656 | 20.2585 | 90.42 | 89.98 | 94.51 | 94.02 | -0.0408 | -0.1495 | 7.6454 | 0.1457 |
| 141.00 | 0.0 | 0.0001 | 50.4136 | 21.3131 | 16.9656 | 20.2585 | 90.42 | 89.98 | 94.51 | 94.02 | -0.0402 | -0.1496 | 7.7969 | 0.1515 |
| 142.00 | 0.0 | 0.0000 | 49.4136 | 21.3131 | 16.9656 | 20.2585 | 90.42 | 89.98 | 94.51 | 94.02 | -0.0395 | -0.1496 | 7.9546 | 0.1576 |
| 143.00 | 0.0 | 0.0000 | 48.4136 | 21.3131 | 16.9656 | 20.2585 | 90.42 | 89.98 | 94.51 | 94.02 | -0.0389 | -0.1496 | 8.1187 | 0.1641 |
| 144.00 | 0.0 | 0.0000 | 46.7969 | 21.3868 | 17.0442 | 20.3373 | 90.42 | 90.27 | 94.51 | 94.32 | -0.0382 | -0.1153 | 8.2897 | 0.1710 |
| 145.00 | 0.0 | 0.0000 | 45.7969 | 21.3868 | 17.0442 | 20.3373 | 90.42 | 90.27 | 94.51 | 94.32 | -0.0376 | -0.1149 | 5.4002 | -2.8895 |
| 146.00 | 0.0 | 0.0000 | 44.7969 | 21.3868 | 17.0442 | 20.3373 | 90.42 | 90.27 | 94.51 | 94.32 | -0.0369 | -0.1145 | 5.5197 | 0.1195 |
| 147.00 | 0.0 | 0.0000 | 43.7969 | 21.3868 | 17.0442 | 20.3373 | 90.42 | 90.27 | 94.51 | 94.32 | -0.0363 | -0.1141 | 5.6446 | 0.1249 |
| 148.00 | 0.0 | 0.0000 | 42.7969 | 21.3868 | 17.0442 | 20.3373 | 90.42 | 90.27 | 94.51 | 94.32 | -0.0357 | -0.1137 | 5.7753 | 0.1307 |
| 149.00 | 0.0 | 0.0000 | 41.7969 | 21.3868 | 17.0442 | 20.3373 | 90.42 | 90.27 | 94.51 | 94.32 | -0.0350 | -0.1133 | 5.9122 | 0.1369 |
| 150.00 | 0.0 | 0.0000 | 42.0859 | 21.3384 | 16.9314 | 20.2242 | 90.42 | 89.84 | 94.51 | 93.89 | -0.0344 | -0.1679 | 6.0557 | 0.1435 |
| 151.00 | 0.0 | 0.0000 | 41.0659 | 21.3384 | 16.9314 | 20.2242 | 90.42 | 89.84 | 94.51 | 93.89 | -0.0337 | -0.1682 | 11.3585 | 5.3028 |
| 152.00 | 0.0 | 0.0000 | 40.0859 | 21.3384 | 16.9314 | 20.2242 | 90.42 | 89.84 | 94.51 | 93.89 | -0.0331 | -0.1684 | 11.6426 | 0.2841 |
| 153.00 | 0.0 | 0.0000 | 39.0859 | 21.3384 | 16.9314 | 20.2242 | 90.42 | 89.84 | 94.51 | 93.89 | -0.0324 | -0.1687 | 11.9413 | 0.2987 |
| 154.00 | 0.0 | 0.0000 | 38.0859 | 21.3384 | 16.9314 | 20.2242 | 90.42 | 89.84 | 94.51 | 93.89 | -0.0318 | -0.1689 | 12.2557 | 0.3144 |
| 155.00 | 0.0 | 0.0000 | 37.0859 | 21.3384 | 16.9314 | 20.2242 | 90.42 | 89.84 | 94.51 | 93.89 | -0.0311 | -0.1692 | 12.5872 | 0.3314 |
| 156.00 | 0.0 | 0.0000 | 36.4294 | 21.2590 | 16.8688 | 20.1615 | 90.42 | 89.61 | 94.51 | 93.65 | -0.0305 | -0.1984 | 12.9370 | 0.3498 |
| 157.00 | 0.0 | 0.0000 | 35.4294 | 21.2590 | 16.8688 | 20.1615 | 90.42 | 89.61 | 94.51 | 93.65 | -0.0298 | -0.1990 | 16.3521 | 3.4161 |
| 158.00 | 0.0 | 0.0000 | 34.4294 | 21.2590 | 16.8688 | 20.1615 | 90.42 | 89.61 | 94.51 | 93.65 | -0.0292 | -0.1996 | 16.8328 | 0.4798 |

| T | PHC | PHI | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 159.00 | 0.0 | 0.0000 | 33.4294 | 21.2590 | 16.8688 | 20.1615 | 90.42 | 89.61 | 94.51 | 93.65 | -0.0286 | -0.2002 | 17.3416 | 0.5087 |
| 160.00 | 0.0 | 0.0000 | 32.4294 | 21.2590 | 16.8688 | 20.1615 | 90.42 | 89.61 | 94.51 | 93.65 | -0.0279 | -0.2008 | 17.8819 | 0.5404 |
| 161.00 | 0.0 | 0.0000 | 31.4294 | 21.2590 | 16.8688 | 20.1615 | 90.42 | 89.61 | 94.51 | 93.65 | -0.0273 | -0.2014 | 18.4570 | 0.5751 |
| 162.00 | 0.0 | 0.0000 | 28.0981 | 21.4655 | 17.1354 | 20.4286 | 90.42 | 90.61 | 94.51 | 94.67 | -0.0266 | -0.0635 | 18.4570 | 0.5751 |
| 163.00 | 0.0 | 0.0000 | 27.0981 | 21.4655 | 17.1354 | 20.4286 | 90.42 | 90.61 | 94.51 | 94.67 | -0.0260 | -0.0625 | 18.4570 | 0.5751 |
| 164.00 | 0.0 | 0.0000 | 26.0981 | 21.4655 | 17.1354 | 20.4286 | 90.42 | 90.61 | 94.51 | 94.67 | -0.0253 | -0.0616 | 18.4570 | 0.5751 |
| 165.00 | 0.0 | 0.0000 | 25.0981 | 21.4655 | 17.1354 | 20.4286 | 90.42 | 90.61 | 94.51 | 94.67 | -0.0247 | -0.0606 | 18.4570 | 0.5751 |
| 166.00 | 0.0 | 0.0000 | 24.0981 | 21.4655 | 17.1354 | 20.4286 | 90.42 | 90.61 | 94.51 | 94.67 | -0.0240 | -0.0597 | 18.4570 | 0.5751 |
| 167.00 | 0.0 | 0.0000 | 23.0981 | 21.4655 | 17.1354 | 20.4286 | 90.42 | 90.61 | 94.51 | 94.67 | -0.0234 | -0.0587 | 18.4570 | 0.5751 |
| 168.00 | 0.0 | 0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 90.42 | 91.19 | 94.51 | 95.28 | -0.0227 | 0.0265 | 18.4570 | 0.5751 |

STARTING TURN T = 169.00 TINTRN = 0.0

| T | PHC | PHI | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 169.00 | -30.0000 | -7.8427 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 90.17 | 90.95 | 94.24 | 95.02 | -0.0222 | 0.0282 | 18.4570 | 0.5751 |
| 170.00 | -30.0000 | -13.6351 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 89.52 | 90.30 | 93.54 | 94.33 | -0.0224 | 0.0292 | 16.4570 | 0.5751 |
| 171.00 | -30.0000 | -17.9133 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 88.57 | 89.36 | 92.52 | 93.32 | -0.0239 | 0.0290 | 18.4570 | 0.5751 |
| 172.00 | -30.0000 | -21.0730 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 87.39 | 88.20 | 91.26 | 92.07 | -0.0269 | 0.0271 | 18.4570 | 0.5751 |
| 173.00 | -30.0000 | -23.4068 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 86.06 | 86.88 | 89.62 | 90.66 | -0.0320 | 0.0233 | 18.4570 | 0.5751 |
| 174.00 | -30.0000 | -25.1304 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 84.60 | 85.44 | 88.26 | 89.11 | -0.0392 | 0.0173 | 18.4570 | 0.5751 |
| 175.00 | -30.0000 | -26.4034 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 83.06 | 83.92 | 86.60 | 87.48 | -0.0487 | 0.0090 | 18.4570 | 0.5751 |
| 176.00 | -30.0000 | -27.3436 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 81.46 | 82.34 | 84.67 | 85.77 | -0.0606 | -0.0017 | 18.4570 | 0.5751 |
| 177.00 | -30.0000 | -28.0381 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 79.81 | 80.70 | 83.09 | 84.01 | -0.0750 | -0.0149 | 18.4570 | 0.5751 |
| 178.00 | -30.0000 | -28.5510 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 78.13 | 79.04 | 81.26 | 82.21 | -0.0921 | -0.0308 | 18.4570 | 0.5751 |
| 179.00 | -30.0000 | -28.9299 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 76.42 | 77.36 | 79.41 | 80.38 | -0.1117 | -0.0492 | 18.4570 | 0.5751 |
| 180.00 | -30.0000 | -29.2096 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 74.70 | 75.65 | 77.54 | 78.54 | -0.1339 | -0.0703 | 18.4570 | 0.5751 |
| 181.00 | -30.0000 | -29.4162 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 72.97 | 73.94 | 75.66 | 76.67 | -0.1588 | -0.0940 | 18.4570 | 0.5751 |
| 182.00 | -30.0000 | -29.5688 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 71.23 | 72.21 | 73.76 | 74.80 | -0.1863 | -0.1203 | 18.4570 | 0.5751 |
| 183.00 | -30.0000 | -29.6815 | 20.9761 | 21.6161 | 17.2921 | 20.5857 | 69.48 | 70.48 | 71.85 | 72.92 | -0.2165 | -0.1493 | 18.4570 | 0.5751 |
| 184.00 | -30.0000 | -29.7648 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 67.72 | 68.75 | 69.94 | 71.03 | -0.2492 | -0.1809 | 18.4570 | 0.5751 |
| 185.00 | -30.0000 | -29.8263 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 65.97 | 67.02 | 68.02 | 69.14 | -0.2846 | -0.2152 | 18.4570 | 0.5751 |
| 186.00 | -30.0000 | -29.8717 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 64.21 | 65.28 | 66.10 | 67.24 | -0.3225 | -0.2519 | 18.4570 | 0.5751 |
| 187.00 | -30.0000 | -29.9052 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 62.46 | 63.54 | 64.18 | 65.34 | -0.3629 | -0.2913 | 18.4570 | 0.5751 |
| 188.00 | -30.0000 | -29.9300 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 60.70 | 61.81 | 62.25 | 63.44 | -0.3738 | -0.3052 | 18.4570 | 0.5751 |
| 189.00 | -30.0000 | -29.9483 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 58.94 | 60.07 | 60.33 | 61.54 | -0.3290 | -0.2563 | 18.4570 | 0.5751 |
| 190.00 | -30.0000 | -29.9618 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 57.19 | 58.33 | 58.40 | 59.64 | -0.2865 | -0.2137 | 18.4570 | 0.5751 |
| 191.00 | -30.0000 | -29.9718 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 55.43 | 56.60 | 56.47 | 57.74 | -0.2465 | -0.1716 | 18.4570 | 0.5751 |
| 192.00 | -30.0000 | -29.9792 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 53.68 | 54.86 | 54.54 | 55.83 | -0.2089 | -0.1319 | 18.4570 | 0.5751 |

| T | PHC | PHI | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 193.00 | -30.0000 | -29.9846 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 51.92 | 53.13 | 52.61 | 53.93 | -0.1739 | -0.0947 | 18.4570 | 0.5751 |
| 194.00 | -30.0000 | -29.9886 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 50.17 | 51.39 | 50.68 | 52.02 | -0.1414 | -0.0600 | 18.4570 | 0.5751 |
| 195.00 | -30.0000 | -29.9916 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 48.41 | 49.66 | 48.75 | 50.12 | -0.1115 | -0.0279 | 18.4570 | 0.5751 |
| 196.00 | -30.0000 | -29.9938 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 46.66 | 47.92 | 46.82 | 48.21 | -0.0842 | 0.0016 | 18.4570 | 0.5751 |
| 197.00 | -30.0000 | -29.9954 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 44.90 | 46.19 | 44.89 | 46.31 | -0.0596 | 0.0285 | 18.4570 | 0.5751 |
| 198.00 | -30.0000 | -29.9966 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 43.15 | 44.46 | 42.96 | 44.40 | -0.0377 | 0.0527 | 18.4570 | 0.5751 |
| 199.00 | -30.0000 | -29.9975 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 41.39 | 42.72 | 41.03 | 42.50 | -0.0184 | 0.0742 | 18.4570 | 0.5751 |
| 200.00 | -30.0000 | -29.9982 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 39.64 | 40.99 | 39.10 | 40.59 | -0.0019 | 0.0930 | 18.4570 | 0.5751 |
| 201.00 | -30.0000 | -29.9986 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 37.88 | 39.25 | 37.17 | 38.69 | 0.0119 | 0.1091 | 18.4570 | 0.5751 |
| 202.00 | -30.0000 | -29.9990 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 36.12 | 37.52 | 35.24 | 36.78 | 0.0229 | 0.1225 | 18.4570 | 0.5751 |
| 203.00 | -30.0000 | -29.9993 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 34.37 | 35.78 | 33.31 | 34.88 | 0.0311 | 0.1330 | 18.4570 | 0.5751 |

TURN ENDING T = 204.00 TINTRN = 35.00

LEG NUMBER 3

LEG START POINT (X,Y) = 50.3553 44.0156
LEG END POINT (X,Y) = 55.3553 52.6758

LEG LENGTH (NM) = 10.00
LEG AZIMUTH (DEG) = 30.00

DESIRED GROUND SPEED (FT/SEC) = 548.13
DESIRED AIR HEADING (DEG) = 28.52

AVG RANGE OF LEG FROM RADAR (NM) = 71.63
AVG AZIMUTH OF LEG FROM RADAR (DEG) = 47.55

TLEG = 110.652

| T | PHC | PHI | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 204.00 | 0.0 | -22.1568 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 32.85 | 34.28 | 31.64 | 33.23 | 0.0368 | 0.1410 | 18.4570 | 0.5751 |
| 205.00 | 0.0 | -16.3645 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 31.73 | 33.18 | 30.41 | 32.02 | 0.0403 | 0.1469 | 18.4570 | 0.5751 |
| 206.00 | 0.0 | -12.0864 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 30.90 | 32.36 | 29.51 | 31.12 | 0.0424 | 0.1513 | 18.4570 | 0.5751 |
| 207.00 | 0.0 | -8.9267 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 30.29 | 31.76 | 28.84 | 30.46 | 0.0433 | 0.1546 | 18.4570 | 0.5751 |
| 208.00 | 0.0 | -6.5931 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 29.84 | 31.31 | 28.34 | 29.97 | 0.0434 | 0.1570 | 18.4570 | 0.5751 |
| 209.00 | 0.0 | -4.8695 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 29.50 | 30.98 | 27.97 | 29.61 | 0.0428 | 0.1583 | 18.4570 | 0.5751 |
| 210.00 | 0.0 | -3.5965 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 29.25 | 30.74 | 27.70 | 29.34 | 0.0419 | 0.1601 | 18.4570 | 0.5751 |

TURN COMPLETE T = 211.00 TINTRN = 42.00

| T | PHC | PHI | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 211.00 | 0.0 | -2.6563 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 29.08 | 30.56 | 27.50 | 29.14 | 0.0405 | 0.1612 | 18.4570 | 0.5751 |
| 212.00 | 0.0 | -1.9619 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.94 | 30.42 | 27.36 | 29.00 | 0.0390 | 0.1619 | -6.9740 | -25.4310 |
| 213.00 | 0.0 | -1.4490 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.84 | 30.32 | 27.25 | 28.89 | 0.0372 | 0.1625 | -6.5221 | 0.4519 |
| 214.00 | 0.0 | -1.0702 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.77 | 30.25 | 27.17 | 28.81 | 0.0353 | 0.1630 | -6.2055 | 0.3166 |

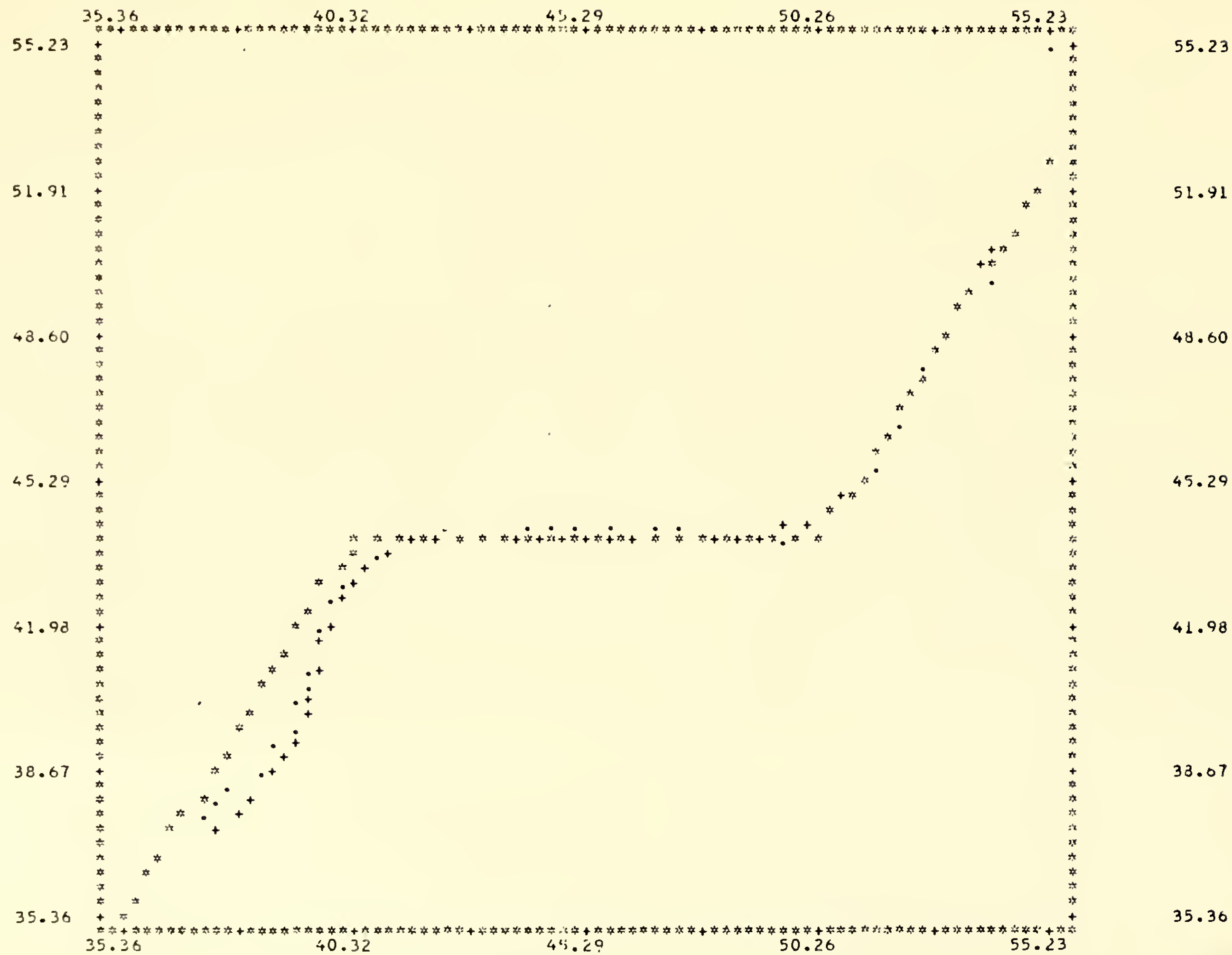
| T | PHC | PH1 | TLEG1 | TTURN1 | TO21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHO1 | PHO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 215.00 | 0.0 | -0.7904 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.71 | 30.20 | 27.11 | 28.75 | 0.0334 | 0.1633 | -5 9893 | 0.2162 |
| 216.00 | 0.0 | -0.5838 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.67 | 30.17 | 27.06 | 28.71 | 0.0313 | 0.1675 | -5.8476 | 0.1417 |
| 217.00 | 0.0 | -0.4312 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.64 | 30.14 | 27.03 | 28.68 | 0.0292 | 0.1677 | -5.8958 | -0.0482 |
| 218.00 | 0.0 | -0.3185 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.62 | 30.12 | 27.01 | 28.66 | 0.0270 | 0.1679 | -5.8510 | 0.0448 |
| 219.00 | 0.0 | -0.2352 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.61 | 30.10 | 26.99 | 28.64 | 0.0249 | 0.1681 | -5.8375 | 0.0135 |
| 220.00 | 0.0 | -0.1737 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.60 | 30.09 | 26.98 | 28.63 | 0.0227 | 0.1683 | -5.8477 | -0.0101 |
| 221.00 | 0.0 | -0.1283 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.59 | 30.08 | 26.97 | 28.62 | 0.0204 | 0.1684 | -5.9757 | -0.0281 |
| 222.00 | 0.0 | -0.0948 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.58 | 29.62 | 26.96 | 28.11 | 0.0182 | 0.0906 | -5.9176 | -0.0419 |
| 223.00 | 0.0 | -0.0700 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.57 | 29.61 | 26.95 | 28.11 | 0.0160 | 0.0900 | -1.5235 | 4.3942 |
| 224.00 | 0.0 | -0.0517 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.57 | 29.61 | 26.95 | 28.10 | 0.0137 | 0.0894 | -1.5250 | -0.0015 |
| 225.00 | 0.0 | -0.0382 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.57 | 29.61 | 26.95 | 28.10 | 0.0115 | 0.0888 | -1.5318 | -0.0068 |
| 226.00 | 0.0 | -0.0282 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.57 | 29.60 | 26.95 | 28.10 | 0.0092 | 0.0882 | -1.5426 | -0.0109 |
| 227.00 | 0.0 | -0.0208 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.57 | 29.60 | 26.94 | 28.10 | 0.0070 | 0.0875 | -1.5567 | -0.0141 |
| 228.00 | 0.0 | -0.0154 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.20 | 26.94 | 27.66 | 0.0047 | 0.0148 | -1.5733 | -0.0166 |
| 229.00 | 0.0 | -0.0114 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.20 | 26.94 | 27.66 | 0.0025 | 0.0135 | 2.6610 | 4.2344 |
| 230.00 | 0.0 | -0.0084 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.20 | 26.94 | 27.66 | 0.0002 | 0.0123 | 2.7037 | 0.0427 |
| 231.00 | 0.0 | -0.0062 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.20 | 26.94 | 27.66 | -0.0021 | 0.0110 | 2.7468 | 0.0431 |
| 232.00 | 0.0 | -0.0046 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.20 | 26.94 | 27.65 | -0.0043 | 0.0097 | 2.7905 | 0.0438 |
| 233.00 | 0.0 | -0.0034 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.20 | 26.94 | 27.65 | -0.0066 | 0.0084 | 2.8352 | 0.0447 |
| 234.00 | 0.0 | -0.0025 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.09 | 26.94 | 27.54 | -0.0088 | -0.0143 | 2.8809 | 0.0457 |
| 235.00 | 0.0 | -0.0018 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.09 | 26.94 | 27.54 | -0.0111 | -0.0158 | 4.2371 | 1.3561 |
| 236.00 | 0.0 | -0.0014 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.09 | 26.94 | 27.54 | -0.0134 | -0.0173 | 4.3071 | 0.0701 |
| 237.00 | 0.0 | -0.0010 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.09 | 26.94 | 27.54 | -0.0156 | -0.0187 | 4.3794 | 0.0723 |
| 238.00 | 0.0 | -0.0007 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.09 | 26.94 | 27.54 | -0.0179 | -0.0202 | 4.4541 | 0.0746 |
| 239.00 | 0.0 | -0.0005 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.09 | 26.94 | 27.54 | -0.0202 | -0.0216 | 4.5312 | 0.0771 |
| 240.00 | 0.0 | -0.0004 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 28.85 | 26.94 | 27.28 | -0.0224 | -0.0701 | 4.6110 | 0.0798 |
| 241.00 | 0.0 | -0.0003 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 28.85 | 26.94 | 27.28 | -0.0247 | -0.0719 | 7.7633 | 3.1523 |
| 242.00 | 0.0 | -0.0002 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 28.85 | 26.94 | 27.28 | -0.0270 | -0.0737 | 7.9061 | 0.1427 |
| 243.00 | 0.0 | -0.0002 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 28.85 | 26.94 | 27.28 | -0.0292 | -0.0756 | 8.0541 | 0.1481 |
| 244.00 | 0.0 | -0.0001 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 28.85 | 26.94 | 27.28 | -0.0315 | -0.0774 | 8.2078 | 0.1537 |
| 245.00 | 0.0 | -0.0001 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 28.85 | 26.94 | 27.28 | -0.0337 | -0.0793 | 8.3675 | 0.1597 |
| 246.00 | 0.0 | -0.0001 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.26 | 26.94 | 27.73 | -0.0360 | 0.0026 | 8.5335 | 0.1660 |
| 247.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.26 | 26.94 | 27.73 | -0.0383 | 0.0014 | 2.8279 | -5.70[illegible] |
| 248.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5657 | 28.56 | 29.26 | 26.94 | 27.73 | -0.0405 | 0.0002 | 2.8856 | 0.[illegible] |
| 249.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.26 | 26.94 | 27.73 | -0.0428 | -0.0010 | 2.9459 | [illegible] |

| T | PHC | PHI | TLEG1 | TTUPN1 | TP21 | TT21 | HTG | HEG | HTA | HEA | ETRUE | EEST | PHD1 | PHD2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 250.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.26 | 26.94 | 27.73 | -0.0451 | -0.0021 | 3.0085 | 0.0627 |
| 251.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.55 | 29.26 | 26.94 | 27.73 | -0.0473 | -0.0033 | 3.0739 | 0.0654 |
| 252.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.13 | 26.94 | 27.58 | -0.0496 | -0.0281 | 3.1422 | 0.0683 |
| 253.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.13 | 26.94 | 27.58 | -0.0518 | -0.0295 | 5.0606 | 1.9184 |
| 254.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.13 | 26.94 | 27.58 | -0.0541 | -0.0309 | 5.1768 | 0.1162 |
| 255.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.13 | 26.94 | 27.58 | -0.0564 | -0.0322 | 5.2985 | 0.1217 |
| 256.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5557 | 28.56 | 29.13 | 26.94 | 27.58 | -0.0586 | -0.0336 | 5.4260 | 0.1275 |
| 257.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.13 | 26.94 | 27.58 | -0.0609 | -0.0350 | 5.5598 | 0.1338 |
| 258.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.37 | 26.94 | 27.84 | -0.0632 | 0.0136 | 5.7004 | 0.1406 |
| 259.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.55 | 29.37 | 26.94 | 27.84 | -0.0654 | 0.0126 | 1.6404 | -4.0600 |
| 260.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.55 | 29.37 | 26.94 | 27.84 | -0.0677 | 0.0116 | 1.6840 | 0.0436 |
| 261.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.37 | 26.94 | 27.84 | -0.0700 | 0.0106 | 1.7300 | 0.0459 |
| 262.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.37 | 26.94 | 27.84 | -0.0722 | 0.0096 | 1.7785 | 0.0485 |
| 263.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.37 | 26.94 | 27.84 | -0.0745 | 0.0086 | 1.8298 | 0.0513 |
| 264.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.39 | 26.94 | 27.86 | -0.0767 | 0.0131 | 1.3842 | 0.0544 |
| 265.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.39 | 26.94 | 27.86 | -0.0790 | 0.0121 | 1.4328 | -0.4514 |
| 266.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.39 | 26.94 | 27.86 | -0.0813 | 0.0112 | 1.4778 | 0.0451 |
| 267.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.39 | 26.94 | 27.86 | -0.0835 | 0.0102 | 1.5258 | 0.0480 |
| 268.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.39 | 26.94 | 27.86 | -0.0858 | 0.0092 | 1.5771 | 0.0512 |
| 269.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.39 | 26.94 | 27.86 | -0.0881 | 0.0083 | 1.6318 | 0.0548 |
| 270.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.56 | 26.94 | 28.04 | -0.0903 | 0.0462 | 1.6906 | 0.0587 |
| 271.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.56 | 26.94 | 28.04 | -0.0926 | 0.0455 | -2.5292 | -4.2198 |
| 272.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.56 | 26.94 | 28.04 | -0.0948 | 0.0447 | -2.6261 | -0.0969 |
| 273.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.56 | 26.94 | 28.04 | -0.0971 | 0.0440 | -2.7307 | -0.1046 |
| 274.00 | 0.0 | -0.0000 | 20.9781 | 21.6161 | 17.2921 | 20.5857 | 28.56 | 29.56 | 26.94 | 28.04 | -0.0994 | 0.0433 | -2.8440 | -0.1133 |

RMS ETRUE = 0.480284
RMS EEST = 0.366266

LENTZ AN/TPQ-27

DESIRED, TRUE, AND ESTIMATED POSITION



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C
C
C**********AN/TPQ-10 SIMULATION PROGRAM FOR PRECISION GUIDANCE**********
C          MOD 2
C
C
C                      ROBERT E. LENTZ
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      COMMON/AIRCOM/X3(3),XD3(3),WT(3),PHB,TB,DT,PHC,
     1             TG,ITH,IB1,PH,PSD,PS,THC,ANH,ATT,TUP,THN,T
C
      COMMON/RADCOM/SIG(6),BIS(3),X2(3),XD2(3),X1(3),XD1(3),
     1             SIGW(3),WR(3),PS1,PH1,XDD1(3),GNX,GNY,
     2             GNZ,IU,NWLD
C
      COMMON/DERCOM/EKDTAB(112),VKDTAB(112),D2W,HT,IPLC,NNT
C
      COMMON/DIFCOM/HMX,HMN,H,EROR,X,XMX,VDR(16,16),N,NAC,IFL,IFX,ISTF
C
C----DIMENSION ALLOCATION FOR PLOT PACKAGE
      REAL*4 XXA(200),XXB(200),XXC(200),XXD(200),XXE(200),
     1XXF(200),XXG(200)
      REAL*4 YYA(200),YYB(200),YYC(200),YYD(200),YYE(200),
     1YYF(200),YYG(200),YYH(200),YYO(200),YYP(200),YYQ(200),YYR(200),
     2YYS(200),YYT(200),YYU(200),YYS1(200),YYS2(200)
      REAL*8 ATITLE(12),BTITLE(12),CTITLE(12),DTITLE(12),ETITLE(12),
     1FTITLE(12),GTITLE(12),HTITLE(12),OTITLE(12),PTITLE(12),QTITLE(12),
     2RTITLE(12),STITLE(12),TTITLE(12),UTITLE(12),VTITLE(12),WTITLE(12),
     3XTITLE(12),YTITLE(12),ZTITLE(12)
C
      DIMENSION X4(3),X5(3),XD5(3),X6(3),XD6(3),X7(3),WH(3),EM1(3,3),
     1EM2(3,3),EV1(3),NTAB(7),NENT(7),GKD(112,7),XKD(112,7),SENCO(6),
     2FILRES(4),SUMSQR(4),EM3(3,3)
C
      EXTERNAL DER,OUT
C
      DATA DEG,RE,WE/57.295779513082321,20926428.,7.292116D-05/
      DATA G,G2/32.174049,16.087007/
      DATA SENCO,FILRES,SUMSQR/6*0.D0,4*0.D0,4*0.D0/
      DATA X4,X5,XD5,X6,XD6/3*0.D0,3*0.D0,3*0.D0,3*0.D0,3*0.D0/
      DATA X7,WH,EM1,EM2/3*0.D0,3*0.D0,9*0.D0,9*0.D0/
      DATA EM3,EV1/9*0.D0,3*0.D0/
      DATA NTAB,NENT,GKD,XKD/7*0,7*0,784*0.D0,784*0.D0/
      DATA NTBP,ITAB1,NSTP,NSAMPL,JTH,KTH/0,0,12,-1,8,16/
      DATA IMOD,LNC,ILVL,JAVG,IIFLG/7,0,0,0,0/
      DATA YNP,TSTF,TF,RSRA,RA,XGC,YGC/7*0.D0/
```

```
      DATA G1,G2,TLVL,TLVL1,THA,TTHD,TP,ENSTP/75.,75.,2.,3.,0.,
     1     13.5,0.,12./
      DATA CTV,XE,XEO,XEEXPN,DXE,HDE,HDEOLD,HDEDOT,PHDAVG/9*0.D0/
      DATA PHD1,PHD2,PHD/3*0.D0/
      DATA ZIP/0.D0/
C
C
C----PRIMARY ARRAY DEFINITIONS
C     X1: STATE ESTIMATION VECTOR IN RADAR COORDINATES
C     X2: TRUE COORDINATES OF AIRCRAFT IN RADAR FRAME
C     X3: TRUE COORDINATES OF AIRCRAFT IN TARGET FRAME
C     X4: USED FOR TEMPORARY STORAGE ONLY
C     X5: ESTIMATED COORDINATES OF THE TARGET IN THE "PRIMED" FRAME
C     X6: ESTIMATED COORDINATES OF TARGET IN THE "DOUBLE PRIMED" SYSTEM
C     X7: ESTIMATED TARGET-AIRCRAFT VECTOR IN RADAR FRAME
C
C     EV1: TRUE TARGET COORDINATES IN THE RADAR FRAME
C     WT: TRUE WIND VECTOR IN THE TARGET FRAME
C     WH: ESTIMATED WIND VECTOR IN THE TARGET FRAME
C     WR: ESTIMATED WIND VECTOR IN THE RADAR FRAME
C
C----NON-ZERO COMMON INITIALIZATIONS
      ITH=-1
      TG=1000.0
      N=16
      IFX=1
      ISTF=0
      NAC=4
      EROR=1.D-06
      XMX=3000.D0
      NWLD=-1
      IU=635897
C
C----READ DATA FOR PROBLEM STARTING WITH POSITION AND RADAR VALUES
      READ(5,2) WT,WH
      READ(5,2) BIS,SIG(4),SIG(5),SIG(6)
      READ(5,2) SIG(1),SIG(2),SIG(3)
      READ(5,2) SIGW
      READ(5,2) X3
      READ(5,2) XD3
      READ(5,3) PHB,TB,DT,DTCON,PHI,TWLD,MWLD
C
C----READ DIVE MODE DATA
      READ(5,2) T3,THNM,THDM,THD,ATT,ATH
      READ(5,102) ANH,TUP,HTOL,ATOL,S,IB1,IACC
C
C----READ TITLES FOR PLOTTED OUTPUT
      READ(5,101) ATITLE,BTITLE,CTITLE,DTITLE,ETITLE,FTITLE,
```

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     1GTITLE,HTITLE,OTITLE,PTITLE,QTITLE,RTITLE,STITLE,TTITLE,UTITLE,
     2VTITLE,WTITLE,XTITLE,YTITLE,ZTITLE
C
C----READ BOMBING DATA TABLE CONSTANTS AND FIND CORRECT TABLE
      READ(5,102) WBLX,WBLY,BFF,D,W,NTB
      READ(5,9)NTABS,(NTAB(I),NENT(I),I=1,NTABS)
      DO 100 I=1,NTABS
      NNT=NENT(I)
  100 READ(5,1)(XKD(J,I),GKD(J,I),J=1,NNT)
C
      IF(NTB.EQ.NTBP)     GO TO 114
      NTBP=NTB
      DO 111 I=1,NTABS
      IF(NTB.EQ.NTAB(I))     GO TO 112
  111 CONTINUE
      WRITE(6,90)NTB
      GO TO 999
  112 NNT=NENT(I)
      DO 113 J=1,NNT
      EKDTAB(J)=GKD(J,I)
  113 VKDTAB(J)=XKD(J,I)
  114 IPLC=NNT/2
      IDTCON=DTCON/DT+0.5
C
C----TH IS THE ANGLE BETWEEN THE TARGET AND THE RADAR
      TH=THNM/THDM
      STH=DSIN(TH/DEG)
      CTH=DCOS(TH/DEG)
C
C----SET UP MATRIX FOR COORDINATE TRANSFORMATION
      EM1(1,1)=1.DO
      EM1(2,2)= CTH
      EM1(2,3)=STH
      EM1(3,2)=-STH
      EM1(3,3)= CTH
C
      EV1(1)=0.DO
      EV1(2)=RE*STH
      EV1(3)=-RE+RE*CTH
C
      DO 11 I=1,3
      DO 11 J=1,3
      EM2(I,J)=EM1(J,I)
      EM3(I,J)=0.DO
   11 IF(I.EQ.J)     EM3(I,J)=1.DO
C
C----PHI IS RADAR LATITUDE
      SPH=DSIN(PHI/DEG)
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      CPH=DCOS(PHI/DEG)                                                 LENT1450
C                                                                       LENT1460
C----TRANSFORM ESTIMATED WIND VALUES FROM TARGET TO                     LENT1470
C    RADAR COORDINATE SYSTEM.                                           LENT1480
      CALL MATMLT(EM1,WH,WR)                                            LENT1490
C                                                                       LENT1500
C----PRINT OUT INITAL VALUES AND CONSTANTS FOR THE PROBLEM              LENT1510
      WRITE(6,5) WT,WH,MWLD,TWLD,SIG(1),SIG(2),SIG(3),BIS,              LENT1520
     1           SIG(4),SIG(5),SIG(6),SIGW,DT,X3,XD3                    LENT1530
      WRITE(6,60) TB,PHB                                                LENT1540
      WRITE(6,61) DTCON,G1,G2                                           LENT1550
      WRITE(6,62) WBLX,WBLY,BFF,D,W,NTB                                 LENT1560
      WRITE(6,63) THD,ATT,ATH,ANH,TUP,HTOL,ATOL,THNM,                   LENT1570
     1            THDM,IB1,IACC                                         LENT1580
C                                                                       LENT1590
C----DIVE EQUATION CONSTANTS                                            LENT1600
C    IB1=0 WHEN IN LEVEL BOMBING MODE                                   LENT1610
      IF(THD.GT.0.D0)      IB1=1                                        LENT1620
      D2W=D*D/(144.D0*W)*BFF                                            LENT1630
      CD4=THD/DEG                                                       LENT1640
      CD1=DEXP(ATH*CD4/ANH)                                             LENT1650
      CD2=(CD1-1.D0)/ATH                                                LENT1660
      CTHD=DCOS(CD4)                                                    LENT1670
      STHD=DSIN(CD4)                                                    LENT1680
      TTHD=STHD/CTHD                                                    LENT1690
      CD4=(ATH+ATH)/(ANH*ANH+4.D0*ATH*ATH)                              LENT1700
      CD3=CD4*(CD1*CD1*(CTHD+.5D0*ANH/ATH*STHD)-1.D0)                   LENT1710
      CD4=CD4*(CD1*CD1*(STHD-.5D0*ANH/ATH*CTHD)+.5D0*ANH/ATH)           LENT1720
      ATTL=ATOL/(DEG*CTHD*CTHD)                                         LENT1730
C                                                                       LENT1740
C********************************************************************** LENT1750
C                                                                       LENT1760
C----BEGIN MAJOR LOOP                                                   LENT1770
C                                                                       LENT1780
   12 ITH=ITH+1                                                         LENT1790
C                                                                       LENT1800
      CALL ARCRFT                                                       LENT1810
C                                                                       LENT1820
C----TRANSFORM FROM TARGET TO RADAR COORDINATE SYSTEM                   LENT1830
      CALL MATMAD(EM1,EV1,X3,X2)                                        LENT1840
      CALL MATMLT(EM1,XD3,XD2)                                          LENT1850
C                                                                       LENT1860
C----ITH=0 ON FIRST TIME THROUGH LOOP                                   LENT1870
C    ITH=N ON NTH TIME THROUGH LOOP                                     LENT1880
C    ITH=-1 ON LAST TIME THROUGH LOOP                                   LENT1890
      IF(ITH.GE.0)      GO TO 14                                        LENT1900
C                                                                       LENT1910
C----SET UP INDICES AND VECTORS FOR LAST TIME THROUGH LOOP              LENT1920
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  125 DO 13 I=1,3
      WH(I)=WT(I)
      CALL MATMLT(EM1,WH,WR)
      X1(I)=X2(I)
   13 XD1(I)=XD2(I)
      JTH=8
      KTH=32
      ITH=-1
      GO TO 15
C
C----GENERATE A TOTAL OF MWLD "WILD" POINTS BEGINNING AT TIME TWLD
C    NWLD SET EQUAL TO MWLD AND DECREMENTED UNTIL NEGATIVE
C    AT THAT TIME WILD POINTS STOP
  14  IF(T.NE.TWLD)      GO TO 141
      NWLD=MWLD
  141 NWLD=NWLD-1
C
      CALL RADAR9
C
C----COMPUTE RADAR ESTIMATION ERROR RESIDUALS
      DUMSUM=0.DO
      IF(ITH.EQ.0) WRITE(6,8)
      NSAMPL=NSAMPL+1
      DO 142 I=1,3
      FILRES(I)=X1(I)-X2(I)
      DUMSUM=DUMSUM+FILRES(I)**2
  142 SUMSQR(I)=SUMSQR(I)+FILRES(I)**2
      FILRES(4)=DSQRT(DUMSUM)
      SUMSQR(4)=SUMSQR(4)+DUMSUM
      IF(ITH.EQ.0) GO TO 18
C
C----X7 CONTAINS ESTIMATE OF TARGET-AIRCRAFT COORDINATES
C     IN THE RADAR FRAME.
   15 DO 16 I=1,3
   16 X7(I)=EV1(I)-X1(I)
C
C----X5 CONTAINS COORDINATES OF THE TARGET IN THE AIRCRAFT
C     (PRIMED) REFERENCE FRAME.
      CALL MATMLT(EM2,X7,X5)
      CALL MATMLT(EM2,XD1.XD5)
C
      CA=DSQRT(XD5(1)*XD5(1)+XD5(2)*XD5(2))
      SA=XD5(1)/CA
      CA=XD5(2)/CA
      EM3(1,1)=CA
      EM3(1,2)=-SA
      EM3(2,1)=SA
      EM3(2,2)=CA
```

```
C
C----X6 CONTAINS COORDINATES OF THE TARGET IN THE AIRCRAFT FRAME,
C    ROTATED SUCH THAT THE XD6(2) VECTOR POINTS AT THE TARGET.
C    NOTE: XD5 AND XD6 ARE ACTUALLY NEGATIVE DERIVATIVES OF XD5/XD6
      CALL MATMLT(EM3,X5,X6)
      CALL MATMLT(EM3,XD5,XD6)
C
      AA=DEG*DARCOS(CA)
      EM3(1,2)=-EM3(1,2)
      EM3(2,1)=-EM3(2,1)
C
      X4(1)=0.D0
      X4(2)=XD6(2)
      X4(3)=XD6(3)
C
C----PUT DATA BACK INTO UNROTATED A/C COORDINATES
      CALL MATMLT(EM3,X4,XD5)
C
      HATS=HAT
      IF(IB1.EQ.0.OR.IB1.EQ.2)      HAT=-X6(3)
C
C----BYPASS DIVE EQUATIONS WHEN IB1=0
      IF(IB1.NE.1)      GO TO 165
      T2=XD6(2)*CD2
      DY2=XD6(2)*XD6(2)
      DZ2=CD4*DY2
      DY2=CD3*DY2
      V2=XD6(2)+ATH*T2
      V3=V2+ATH*T3
      DY3=.5D0*T3*(V2+V3)
      DZ3=DY3*STHD
      DY3=DY3*CTHD
      VH=V3*CTHD
      VV=-V3*STHD
      HAT=-X6(3)-DZ2-DZ3
      X4(1)=VH*SA-WH(1)
      X4(2)=VH*CA-WH(2)
      X4(3)=VV
      GO TO 170
C
C----SUBTRACT EST WIND VALUES AT ALT OF TARGET IN A/C COORDINATES
  165 DO 17 I=1,3
   17 X4(I)=XD5(I)-WH(I)
  170 VE2=X4(1)*X4(1)+X4(2)*X4(2)
C
C----VEH IS HORIZONTAL AIRSPEED
C    VE IS TOTAL AIRSPEED
C    DOWNWARD VELOCITY ANGLE(THE) IS SET TO ZERO IN LEVEL BOMB MODE
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C     HA IS TOTAL HEIGHT OF TARGET ABOVE SEA LEVEL
       VEH=DSQRT(VE2)
       SG=X4(1)/VEH
       CG=X4(2)/VEH
       SAG=SA*CG-CA*SG
       CAG=CA*CG+SA*SG
       IF(IB1.NE.2.OR.XD6(3).GE.-.100*VEH)      GO TO 171
       IB1=3
       TP=T
       HAT=HATS
  171  VE2=VE2+X4(3)*X4(3)
       VE=DSQRT(VE2)
       THE=0.D0
       IF(ITH.LT.0.OR.IB1.GT.1)      THE=DATAN2(X4(3),VEH)*DEG
       IF(IB1.EQ.0.AND.ITH.GE.0)      X4(3)=0.D0
       HA=HAT+HT
       VDR(1,2)=HA
       VDR(1,3)=VEH
       VDR(1,4)=X4(3)
C
C----BRANCH AROUND TIME OF FALL(TF) AND BALLISTIC RANGE(RA)
C     EQUATIONS WHEN TOTAL ELAPSED TIME IS LESS THAN 2 SECONDS
       IF(ITH.LT.0) GO TO 173
       IF(ITH.LE.48)     GO TO 18
C
C----TF AND RA ARE COMPUTED ON EACH LOOP, THROUGH THE USE OF PARTIAL
C     DERIVATIVES WHICH ARE CALCULATED EVERY 4 SECONDS, STARTING AT T=2
  173  TF=TFTF+(HA-DSV)*SENCO(1)+(VEH-DXSV)*SENCO(2)+(X4(3)-DZSV)*SENCO(3
      1)
       RA=RARA+(HA-DSV)*SENCO(4)+(VEH-DXSV)*SENCO(5)+(X4(3)-DZSV)*SENCO(6
      1)
   18  JTH=JTH+1
       IF(JTH.EQ.9)     JTH=1
       KTH=KTH+1
C
C----BRANCH AROUND INTERGRATOR UNLESS 4 SECONDS HAVE ELAPSED SINCE LAST
       IF(KTH.LT.33)     GO TO 205
       KTH=1
C
C----STORE INITIAL CONDITIONS FOR NEXT 4 SECONDS EXTRAPOLATION
       DSV=ZSV
       DXSV=XDSV
       DZSV=ZDSV
       RARA=FSRA
       TFTF=TSTF
C
C----STORE PARTIAL VALUES FOR NEXT 4 SECONDS EXTRAPOLATION
       DO 183 I=1,6
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  183 SENCO(I)=VDR(4,I)                                                   LENT3370
      ZSV=HA                                                              LENT3380
      XDSV=VDR(1,3)                                                       LENT3390
      ZDSV=VDR(1,4)                                                       LENT3400
      VDR(1,1)=0.D0                                                       LENT3410
      DO 19 I=5,15                                                        LENT3420
   19 VDR(1,I)=0.D0                                                       LENT3430
      VDR(1, 8)=1.D0                                                      LENT3440
      VDR(1,12)=1.D0                                                      LENT3450
      VDR(1,16)=1.D0                                                      LENT3460
      H=DSQRT(HA/10.D0)/ENSTP                                             LENT3470
      X=0.D0                                                              LENT3480
C                                                                         LENT3490
      CALL STIFF(DER,OUT)                                                 LENT3500
C                                                                         LENT3510
      RSRA=VDR(1,1)                                                       LENT3520
      TSTF=X                                                              LENT3530
      JTH=JTH-1                                                           LENT3540
      KTH=KTH-1                                                           LENT3550
      IF(ITH.GE.0)      GO TO 173                                         LENT3560
C                                                                         LENT3570
      RA=RSRA                                                             LENT3580
      TF=X                                                                LENT3590
C                                                                         LENT3600
C----ON INITAL 6 SECONDS OF RUN, BRANCH BACK TO BEGINNING                 LENT3610
 205  IF(ITH.GE.48.OR.ITH.LT.0) GO TO 2050                                LENT3620
      GO TO 306                                                           LENT3630
C                                                                         LENT3640
C----BALLISTIC WIND CALCULATIONS                                          LENT3650
2050  WBX=WBLX*CA-WBLY*SA                                                 LENT3660
      WBY=WBLX*SA+WBLY*CA                                                 LENT3670
      P=0.D0                                                              LENT3680
      OMP=1.D0                                                            LENT3690
C                                                                         LENT3700
C----BYPASS DIVE EQUATIONS                                                LENT3710
      IF(IB1.NE.2.AND.IB1.NE.3)      GO TO 20500                          LENT3720
      P=(HAT-HPF)/(HO-HPF)                                                LENT3730
      IF(P.GT.1.D0)       P=1.D0                                          LENT3740
      IF(P.LT.0.D0)       P=0.D0                                          LENT3750
      OMP=1.D0-P                                                          LENT3760
      TF=P*TPF+OMP*TF                                                     LENT3770
      RA=P*RAF+OMP*RA                                                     LENT3780
      IF(IB1.EQ.2)       HAT=HPF                                          LENT3790
C                                                                         LENT3800
C----COMPUTE BOMB IMPACT POINT.  XGC,YGC, AND ZGC                         LENT3810
C     ARE THE IMPACT POINT COORDINATES CORRECTED FOR                      LENT3820
C     CORRECLIS ACCELERATION                                              LENT3830
20500 XG=WBX*TF-RA*SAG                                                    LENT3840
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      IF(TF.LT.0.000001)TF=0.000001                                     LENT3850
      YG=WBY*TF+RA*CAG                                                  LENT3860
      DXG=WE*TF*(HAT*CPH*CA+RA*SPH)                                     LENT3870
      DYG=WE*TF*HAT*CPH*SA                                              LENT3880
      DZG=WE*TF*RA*CPH*SA                                               LENT3890
      XGC=XG+DXG                                                        LENT3900
      YGC=YG+DYG                                                        LENT3910
      ZGC=DZG                                                           LENT3920
      IF(IB1.GT.0)      GO TO 2051                                      LENT3930
C                                                                       LENT3940
C----COMPUTE TIME TO GO TO RELEASE BOMB(TG) AND LATERAL ERROR(XE)       LENT3950
      TG=(X6(2)-YGC)/XD6(2)                                             LENT3960
      XEO=XE                                                            LENT3970
      XE=X6(1)-XGC                                                      LENT3980
      IF(ITH.EQ.48) XELIM=.05*XE                                        LENT3990
      IF(XE.LE.XELIM) IIFLG=1                                           LENT4000
      IF(IIFLG.EQ.1) XEEXPN=XE                                          LENT4010
      GO TO 2059                                                        LENT4020
C                                                                       LENT4030
C----FOLLOWING BLOCK OF EQUATIONS BYPASSED UNLESS IN DIVE MODE          LENT4040
 2051 IF(IB1.GT.1)      GO TO 2052                                      LENT4050
      XE=X6(1)-XGC                                                      LENT4060
      TP=(X6(2)-YGC-DY2-DY3)/XD6(2)                                     LENT4070
      TG=TP+T2+T3                                                       LENT4080
      IF(TP.GT.0.D0)      GO TO 2059                                    LENT4090
      IB1=2                                                             LENT4100
      TP=T                                                              LENT4110
      TPF=TF                                                            LENT4120
      RAF=RA                                                            LENT4130
      HPF=HAT                                                           LENT4140
      HO=-X6(3)                                                         LENT4150
      THC=THD                                                           LENT4160
      GO TO 2059                                                        LENT4170
 2052 IF(IB1.GT.2)      GO TO 2053                                      LENT4180
      TG=(X6(2)-YGC)/XD6(2)                                             LENT4190
      GO TO 2054                                                        LENT4200
 2053 TG=(X6(3)+HAT)/XD6(3)                                             LENT4210
 2054 YPPA=TG*XD6(2)                                                    LENT4220
      ZPPA=TG*XD6(3)                                                    LENT4230
      YPP1=YPPA+YGC                                                     LENT4240
      XPPM=X6(1)-XGC                                                    LENT4250
      YPPM=X6(2)-YPP1                                                   LENT4260
      DTG=YPPM/(XD6(2)+XD6(3)*OMP*(SENCO(4)*CAG+WBY*SENCO(1)))          LENT4270
      TG=TG+DTG                                                         LENT4280
      XE=XPPM-DTG*XD6(3)*OMP*(-SENCO(4)*SAG+WBX*SENCO(1))               LENT4290
      IF(IB1.GT.2)      GO TO 2055                                      LENT4300
      HAT=-X6(3)+XD6(3)*TG                                              LENT4310
      GO TO 2056                                                        LENT4320
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 2055 HAT=HAT+XD6(3)*DTG
 2056 IF(IB1.EQ.4)       GO TO 2059
      IF((HAT-HPF).GT.HTOL.AND.(TTHD+XD6(3)/XD6(2)).GT.ATTL)    GOTO2059
      IB1=4
      TP=T
      THC=DEG*DATAN(-XD6(3)/XD6(2))
C
C----X6 AND XD6 AT THIS POINT ARE ERRORS IN ESTIMATED A/C
C    POSITION AND VELOCITY IN ROTATED A/C SYSTEM
 2059 DO 206 I=1,3
      X5(I)=-X5(I)
      X6(I)=X3(I)-X5(I)
  206 XD6(I)=XD3(I)-XD5(I)
C
C----RBT IS HORIZONTAL DISTANCE BETWEEN A/C AND TARGET
C    HDE IS THE ANGLE BETWEEN BOMB IMPACT AND THE TARGET IN DEGREES
C    HDEDOT IS THE ANGLE ERROR RATE
C    CTV IS CROSS TRACK VELOCITY
      RBT=DSQRT(X5(1)*X5(1)+X5(2)*X5(2))
      HDEOLD=HDE
      HDE=DARSIN(XE/RBT)*DEG
      HDEDOT=(HDE-HDEOLD)/DT
      IF(DABS(T-6.).LE.0.0001) HDEDOT=0.DO
C
C----IF T IS LESS THAN 20 SECS AND TG IS LESS THAN 2 SECS,
C    SET A DUMMY TIME TO GO(TQ) EQUAL TO 3 SECS
      TQ=TG
      IF(T.GT.20.0) GO TO 207
      IF(TQ.LE.2.) TQ=3.
  207 IF(ITH.LT.0)       GO TO 209
C
C----IF TG IS LESS THAN ZERO, BRANCH FOR LAST TIME THROUGH LOOP
      IF(TG.LE.0.DO)      GO TO 125
      IF(IB1.GT.0.AND.IB1.LT.4)      TG=1000.DO
      CTV=-XE*VEH/RBT
      DXE=(XE-XEO)/DT
      IF(DABS(T-6.).LE.0.0001) DXE=0.DO
C
C----GENERATE CONTROL COMMAND BANK ANGLE
C    PHD1 IS COMPONENT BASED ON ANGLE ERROR HDE
C    PHD2 IS COMPONENT BASED ON ANGLE ERROR RATE HDEDOT
C    PHD IS REQUESTED COMMAND ANGLE IN DEGREES
C    GENERATE NEW COMMAND EVERY DTCON SECONDS
      IF(MOD(ITH,IDTCON).NE.0) GO TO 2082
      PHD1=G1*HDE
      PHD2=G2*HDEDOT
      PHD=PHD1+PHD2
C
```

```
C----ILVL IS INITIALIZED TO ZERO AND SET TO 1 ONLY AFTER TIME TG         LENT4810
C    IS FOUND LESS THAN TLVL, WHICH IS THE TIME AT THE END ON MISSION    LENT4820
C    FOR WHICH NO COMMANDS ARE TO BE SENT                                LENT4830
2082  IF(ILVL.EQ.1)        GO TO 2087                                    LENT4840
      IF(TQ.LE.TLVL)        GO TO 20855                                  LENT4850
      IF(TQ.GT.TLVL1)        GO TO 2086                                  LENT4860
      PHDAVG=PHDAVG+PH1                                                  LENT4870
      JAVG=JAVG+1                                                        LENT4880
      GO TO 2086                                                         LENT4890
20855 ILVL=1                                                             LENT4900
      PHD=PHDAVG/FLOAT(JAVG)                                             LENT4910
C                                                                        LENT4920
C----COMPUTE BANK COMMAND, PHC TO NEAREST 15/128 OF A DEGREE             LENT4930
C    PHC IS LIMITED TO PLUS OR MINUS 30 DEGREES                          LENT4940
 2086 PHC=(PHD)*128.D0/15.D0+.5D0                                        LENT4950
      IF(PHC.LT.0.D0)      PHC=PHC-1.D0                                  LENT4960
      NHC=PHC                                                            LENT4970
      PHC=NHC                                                            LENT4980
      PHC=PHC*15.D0/128.D0                                               LENT4990
      IF(PHC.GT.29.8828125)       PHC=29.8828125                         LENT5000
      IF(PHC.LT.-30.D0)      PHC=-30.D0                                  LENT5010
C                                                                        LENT5020
C----IF COMPUTED TIME TO GO IS LESS THAN THE SAMPLING INTERVAL           LENT5030
C    SET TG=TQ                                                           LENT5040
2087  IF(TQ.LT.DT)      ITH=-2                                           LENT5050
      IF(TQ.LT.DT)      TG=TQ                                            LENT5060
C                                                                        LENT5070
C----GO TO 209 TO PRINT OUTPUT FOR THIS TIME THROUGH LOOP                LENT5080
      IF(NWLD.GT.-2)      GO TO 209                                      LENT5090
 306  IMOD=IMOD+1                                                        LENT5100
      IF(TG.LE.1.0) IMOD=8                                               LENT5110
      IF(IMOD.NE.8) GO TO 12                                             LENT5120
      IMOD=0                                                             LENT5130
      IF(ITH.LT.48) GO TO 209                                            LENT5140
C                                                                        LENT5150
C----STORE VALUES FOR PLOTTING EVERY SECOND                              LENT5160
      ITAB1=ITAB1+1                                                      LENT5170
      XXA(ITAB1)=T                                                       LENT5180
      XXB(ITAB1)=FILPES(1)                                               LENT5190
      XXC(ITAB1)=FILRES(2)                                               LENT5200
      XXD(ITAB1)=FILRES(3)                                               LENT5210
      XXE(ITAB1)=FILRES(4)                                               LENT5220
      XXF(ITAB1)=X6(1)                                                   LENT5230
      XXG(ITAB1)=X6(2)                                                   LENT5240
      YYA(ITAB1)=XE                                                      LENT5250
      YYB(ITAB1)=XEEXPN                                                  LENT5260
      YYC(ITAB1)=DXE                                                     LENT5270
      YYD(ITAB1)=PHD                                                     LENT5280
```

```
      YYE(ITAB1)=PHD1
      YYF(ITAB1)=PHD2
      YYG(ITAB1)=PHC
      YYH(ITAB1)=PH1
      YYO(ITAB1)=PH
C     YYP(ITAB1)=
      YYQ(ITAB1)=XDD1(1)
      YYR(ITAB1)=XDD1(2)
C     YYS(ITAB1)=
C     YYS1(ITAB1)=
C     YYS2(ITAB1)=
C     YYT(ITAB1)=
C     YYU(ITAB1)=
C
C----PRINT SUMMARY OF VALUES EACH SECOND
 209  PRINT 4, X1,XD1,XDD1(1),XDD1(2),
     1         X2,XD2,TF,RA,
     2         X3,XD3,XGC,YGC,
     3         X5,XD5,AA,HAT,
     4         X6,XD6,YNP,ZIP,
     5         PHD1,PHD2,PHD,HDE,HDEDOT,TG,VEH,THN,
     6         PH,PH1,PHC,PS,PS1,ZIP,ZIP,ZIP,
     7         XE,DXE,CTV,ZIP,GNX,GNY,GNZ,T
C----LNC KEEPS TRACK OF NUMBER OF OUTPUTS ON A PAGE, AND THE WRITE
C     STATEMENT YIELDS A NEW PAGE
      IF(ITH.EQ.-1) GO TO 22
      LNC=LNC+1
      IF(LNC.LT.7) GO TO 21
      LNC=0
      WRITE(6,8)
C----LIMIT OF 2000 ITERATIONS PER PROBLEM
   21 IF(ITH.LE.2000)      GO TO 12
C
C----CALCULATE AND PRINT FINAL ERROR SUMMARY, RESIDUAL VALUES
C     AND BIAS ESTIMATE AT PROBLEM TERMINATION
   22 X1(1)=XGC
      X1(2)=YGC
      X1(3)=0.D0
      X3(3)=0.D0
      CALL MATMAD(EM3,X3,X1,X2)
      X2(3)=DSQRT(X2(1)*X2(1)+X2(2)*X2(2))
      DO 1010 I=1,4
1010  SUMSQR(I)=DSQRT(SUMSQR(I)/NSAMPL)
      PRINT 7,X2,SUMSQR
C
C----EXECUTE PLOTS
      WRITE(6,991) ATITLE
      CALL PLOTP(XXA,XXB,ITAB1,0)
```

```
      WRITE(6,991) BTITLE
      CALL PLOTP(XXA,XXC,ITAB1,0)
      WRITE(6,991) CTITLE
      CALL PLOTP(XXA,XXD,ITAB1,0)
      WRITE(6,991) DTITLE
      CALL PLOTP(XXA.XXE,ITAB1,0)
      WRITE(6,991) ETITLE
      CALL PLOTP(XXA,XXF,ITAB1:0)
      WRITE(6,991) FTITLE
      CALL PLOTP(XXA,XXG,ITAB1,0)
      WRITE(6,991) GTITLE
      CALL PLOTP(XXF,XXG,ITAB1,0)
      WRITE(6,991) HTITLE
      CALL PLOTP(XXA,YYA,ITAB1,0)
      WRITE(6,991) OTITLE
      CALL PLOTP(XXA,YYB,ITAB1,0)
      WRITE(6.991) PTITLE
      CALL PLOTP(XXA,YYC,ITAB1,0)
      WRITE(6,991) QTITLE
      CALL PLOTP(XXA,YYD,ITAB1,1)
      CALL PLOTP(XXA,YYE,ITAB1,2)
      CALL PLOTP(XXA,YYF,ITAB1,3)
      WRITE(6,991) RTITLE
      CALL PLOTP(XXA,YYG,ITAB1,1)
      CALL PLOTP(XXA,YYH,ITAB1,2)
      CALL PLOTP(XXA,YYO,ITAB1,3)
      WRITE(6,991) TTITLE
      CALL PLOTP(XXA,YYQ,ITAB1,0)
      WRITE(6,991) UTITLE
      CALL PLOTP(XXA,YYR,ITAB1,0)
      WRITE(6,991) VTITLE
      CALL PLOTP(YYQ,YYR,ITAB1,0)
C     WRITE(6,991) WTITLE
C     WRITE(6,991) XTITLE
C     WRITE(6,991) YTITLE
C     WRITE(6,991) ZTITLE
      PRINT 992
  999 CONTINUE
      STOP
C
C----INPUT FORMAT STATEMENTS
    1 FORMAT(12F6.0)
C
    2 FORMAT(6F10.3)
C
    3 FORMAT(6F10.3,I3)
C
  101 FORMAT(6A8)
```

```
C
 102  FORMAT(5F10.3,2I3)
C
C----OUTPUT FORMAT STATEMENTS
C
   4 FORMAT(/2X,  8D16.5/(2X,8D16.5))
C
   5  FORMAT(1H1,48X,'AN/TPQ-27 SIMULATION',//,37X,'PRECISION ',
     1'GUIDANCE MODE WITH KALMAN FILTERING',///,5X,'INITIAL CONDITIONS :
     2',//,8X,'TRUE WIND AT TARGET = ',10X,1P3D16.5,/,8X,
     3'ESTIMATED WIND AT TARGET = ',5X,1P3D16.5,//,8X,
     4'RADAR DATA',/,10X,
     5'NUMBER OF NOISY POINTS(NWLD) = ',I5,/,10X,
     C'START TIME OF WILD POINTS = ',5X,0PF7.3,/10X,
     6'MEASUREMENT SIGMAS(R(FT.),AZ(MRAD),EL(MRAD)) = ',1P3D16.5,/,10X
     7,'MEASUREMENT BIASES(                "                ) = ' ,1P3D16.5,/,
     810X,'INITIAL VELOCITY MEASUREMENT VALUES = ',9X,1P3D16.5,/,
     910X,'RANDOM FORCING ASSUMPTION VALUES (SIGW) = ',5X,1P3D16.5,/,
     110X,'RADAR SAMPLING INTERVAL = ',26X,0PF6.4,//,8X,
     2'INITIAL POSITION OF A/C IN TARGET SYSTEM = ',1P3D16.5,/,8X,
     3'INITIAL VELOCITY OF A/C IN TARGET SYSTEM = ',1P3D16.5,///)
C
  60  FORMAT(5X,'AIRCRAFT PARAMETERS :',//,9X,'TB = ',F8.5,6X,'PHB = ',
     1F8.5,///)
C
  61  FORMAT(5X,'CONTROL PARAMETERS:',//,9X,'DTCON = ',
     1F8.5,/,9X,'G1 = ',F8.4,/,9X,'G2 = ',F8.4,///)
C
  62  FORMAT(5X,'BALLISTIC TABLE PARAMETERS:',//,9X,
     1'BALLISTIC WIND VALUES (WBLX,WBLY) = ',2F10.6,/,9X,
     2'BFF = ',F10.6,/,9X,'D = ',2X,F10.6,/,9X,
     3'W = ',2X,F10.6,/,9X,'NTB = ',I5,///)
C
  63  FORMAT(5X,'DIVE BOMBING MODE PARAMETERS:',//,9X,
     1'THD = ',F8.2,6X,'ATT = ',F8.2,/,9X,
     2'ATH = ',F8.2,6X,'ANH = ',F8.2,/,9X,
     3'TUP = ',F8.2,5X,'HTOL = ',F8.2,/,8X,
     4'ATOL = ',F8.2,5X,'THNM = ',F8.2,/,8X,
     5'THDM = ',F8.2,6X,'IBL = ',I5,/,8X,
     6'IACC = ',I5,///)
C
   8  FORMAT(1H1,//,59X,'OUTPUT FORMAT',//,
     111X,'X1',14X,'Y1',14X,'Z1',13X,'XD1',13X,'YD1',13X,'ZD1',12X,
     2'XDD1',12X,'YDD1',/,
     311X,'X2',14X,'Y2',14X,'Z2',13X,'XD2',13X,'YD2',13X,'ZD2',12X,
     4'  TF',12X,'  RA',/,
     511X,'X3',14X,'Y3',14X,'Z3',13X,'XD3',13X,'YD3',13X,'ZD3',13X,
     6'XGC',13X,'YGC',/,
```

```
     711X,'X5',14X,'Y5',14X,'Z5',13X,'XD5',13X,'YD5',13X,'ZD5',14X,          LENT6730
     8'AA',13X,'HAT',/,                                                     LENT6740
     911X,'X6',14X,'Y6',14X,'Z6',13X,'XD6',13X,'YD6',13X,'ZD6',10X,          LENT6750
     03X,'YNP',/,                                                           LENT6760
     19X,'PHD1',12X,'PHD2',13X,'PHD',13X,'HDE',10X,'HDEDOT',14X,'TG',       LENT6770
     213X,'VEH',13X,'THN',/,                                                LENT6780
     311X,'PH',13X,'PH1',13X,'PHC',14X,'PS',13X,'PS1',/,                    LENT6790
     411X,'XE',13X,'DXE',13X,'CTV',10X,'          ',10X,                    LENT6800
     5'G(1,1)',10X,'G(4,2)',10X,'G(7,3)',15X,'T',//)                        LENT6810
C                                                                           LENT6820
    9 FORMAT(26I3)                                                          LENT6830
C                                                                           LENT6840
   7  FORMAT(//25X,4HXI =1PD13.5,6X,4HYI =D13.5,6X,4HRI =D13.5,             LENT6850
     1///,20X,'AVG X RESIDUAL = ',0PF10.4,5X,'AVG Y RESIDUAL = ',           LENT6860
     2F10.4,5X,'AVG Z RESIDUAL = ',F10.4,//,49X,                            LENT6870
     3'AVG RADIAL RESIDUAL = ',F10.4, ///)                                  LENT6880
C                                                                           LENT6890
   90 FORMAT(//49X,I6,27H IS AN ILLEGAL TABLE NUMBER)                       LENT6900
C                                                                           LENT6910
 991  FORMAT(1H1,10X,6A8,//,11X,6A8,///)                                    LENT6920
C                                                                           LENT6930
 992  FORMAT(1H1)                                                           LENT6940
C                                                                           LENT6950
      END                                                                   LENT6960
C                                                                           LENT6970
C                                                                           LENT6980
C                                                                           LENT6990
C                                                                           LENT7000
C                                                                           LENT7010
C                                                                           LENT7020
C                                                                           LENT7030
C                                                                           LENT7040
      SUBROUTINE ARCRFT                                                     LENT7050
C                                                                           LENT7060
      IMPLICIT REAL*8 (A-H,O-Z)                                             LENT7070
C                                                                           LENT7080
      COMMON/AIRCOM/X3(3),XD3(3),WT(3),PHB,TB,DT,PHC,                       LENT7090
     1               TG,ITH,IB1,PH,PSD,PS,THC,ANH,ATT,TUP,THN,T             LENT7100
C                                                                           LENT7110
      DATA DEG,G/57.2957795130823 21,32.174049/                             LENT7120
C                                                                           LENT7130
C----FIRST TIME THROUGH, ITH=0                                              LENT7140
      IF(ITH)5,1,4                                                          LENT7150
C                                                                           LENT7160
C----SUBTRACT WIND VELOCITY                                                 LENT7170
    1 SM1=XD3(1)-WT(1)                                                      LENT7180
      SM2=XD3(2)-WT(2)                                                      LENT7190
C                                                                           LENT7200
```

```
C----VT IS AIRSPEED OF A/C
C     PHB IS AUTOPILOT BANK ANGLE BIAS
C     TB IS A/C RESPONSE LOOP TIME CONSTANT
C     PS IS INITIAL TURN ANGLE
C     PSD IS INITIAL TURN RATE
      VT=DSQRT(SM1*SM1+SM2*SM2)
      PH=PHB
      CA1=G/VT
      CA2=DEXP(-DT/TB)
      CA3=CA1
      CA4=DT*DT/(12.D0*DEG)
      CA5=TB*(1.D0-CA2)
      DT3=.5D0*DT
      PSD=CA1*PH
      PS=DATAN2(SM1,SM2)
      CPS=DCOS(PS)
      SPS=DSIN(PS)
      PS=PS*DEG
C
C----EQUATIONS AND CONSTANTS FOR DIVE MODE FOLLOW
      AT1=ATT*DT3
      VTC=VT
      VTH=VT
      TH=0.D0
      THD=TH
      THN=TH
      THDN=TH
      STH=TH
      STHN=TH
      CTH=1.D0
      CTHN=CTH
      DTP=1.D0/TUP
      CA6=DEXP(-DT/TUP)
      AND=ANH*DEG
      AN8=AND*DT
      RETURN
C
C*************************************************************************
C----ENTER MAIN CALCULATION STREAM
C
C----PHC IS NOW THE COMMAND BANK ANGLE AT T(N-1)
C     PHN IS THE NEW BANK ANGLE
C     PSDN IS THE NEW TURNING RATE
C     PSN IS NEW HEADING ANGLE FOR VELOCITY WITH RESPECT TO WIND
    4 T=T+DT
      PSN=PHB+PHC
      PHN=PSN+(PH-PSN)*CA2
      PSDN=CA1*PHN
```

```
      PSN=PS+CA3*(PSN*DT+CA5*(PH-PSN))
      CPSN=PSN/DEG
      SPSN=DSIN(CPSN)
      CPSN=DCOS(CPSN)
C
C----BYPASS FOLLOWING BLOCK OF EQUATIONS UNLESS IN DIVE MODE
      IF(IB1.LE.1)      GO TO 43
      VTO=VT
      VTH=VT+AT1
      VT=VTH+AT1
      CA1=G/VT
      CA3=G/VTH
      THDN=AND/VT
      THN=(THC-TH)*DTP
      IF(DABS(THN).GT.THDN)      GO TO 41
      THDN=THN*CA6
      THN=THC-TUP*THDN
      GO TO 42
   41 THN=AN8/VTH+TH
   42 CTHN=THN/DEG
      STHN=DSIN(CTHN)
      CTHN=DCOS(CTHN)
C
C----UPDATE VELOCITY VECTOR FOR NEW TURN ANGLE
   43 XD3(1)=WT(1)+VT*SPSN*CTHN
      XD3(2)=WT(2)+VT*CPSN*CTHN
      XD3(3)=-VT*STHN
C
C----UPDATE POSITION VECTOR FOR NEW TURN ANGLE
      SM1=DT3*(SPS*CTH+SPSN*CTHN)-CA4*(CPSN*CTHN*PSDN-SPSN*STHN*THDN-CPS
     1      *CTH*PSD+SPS*STH*THD)
      SM2=DT3*(CPS*CTH+CPSN*CTHN)-CA4*(-SPSN*CTHN*PSDN-CPSN*STHN*THDN+
     1      SPS*CTH*PSD-CPS*STH*THD)
      SM3=DT3*(STH+STHN)-CA4*(CTHN*THDN-CTH*THD)
C
      X3(1)=DT*WT(1)+VTH*SM1+X3(1)
      X3(2)=DT*WT(2)+VTH*SM2+X3(2)
      X3(3)=-VTH*SM3+X3(3)
C
C----RESET VALUES FOR NEXT TIME IN SUBROUTINE
      PH=PHN
      PS=PSN
      PSD=PSDN
      SPS=SPSN
      CPS=CPSN
C
      TH=THN
      THD=THDN
```

```
      STH=STHN
      CTH=CTHN
      RETURN
C
C----ENTER THIS SECTION ONLY ON LAST TIME THROUGH MAIN LOOP
C    RECOMPUTE CONSTANTS FOR LAST DELTAT
    5 DT=TG
      DT3=.5D0*DT
      AN8=AND*DT
      CA6=DEXP(-DT/TUP)
      CA2=DEXP(-DT/TB)
      CA5=TB*(1.D0-CA2)
      CA4=DT*DT/(12.D0*DEG)
      AT1=ATT*DT2
      GO TO 4
      END
C
C
C
C
C
C
C
C
      SUBROUTINE RADAR9
C
C----THIS SUBROUTINE SIMULATES A RADAR PROCESSOR.  IT CONVERTS FROM
C    CARTESIAN TO SPHERICAL, ADDS NOISE, AND THEN CONVERTS BACK TO
C    CARTESIAN COORDINATES.  DATA IS FILTERED USING A
C    THIRD ORDER KALMAN FILTER WITH DETERMINSITIC FORCING FROM THE
C    AIRCRAFT CONTROLLER INCLUDED.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 RAN(3)
C
      COMMON/AIRCOM/X3(3),XD3(3),WT(3),PHB,TB,DT,PHC,
     1              TG,ITH,IB1,PH,PSD,PS,THC,ANH,ATT,TUP,THN,T
C
      COMMON/RADCOM/SIG(6),BIS(3),X2(3),XD2(3),X1(3),XD1(3),
     1              SIGW(3),WR(3),PS1,PH1,XDD1(3),GNX,GNY,
     2              GNZ,IU,NWLD
C
      DIMENSION Q(9,9),GAMMA(9,9),ADUM(9,9),BDUM(9,9),W(9,9),
     1PP(9,9),PE(9,9),H(9,9),HT(9,9),R(9,9),PHI(9,9),SIG1(3),
     2PHITRN(9,9),G(9,9),XIDENT(9,9),X1P(3),XD1P(3),XDD1P(3),
     3XDATA(3),DELX(3)
C
      EQUIVALENCE (XDATA(1),RR),(XDATA(2),A),(XDATA(3),E)
```

```
C
      DATA DEG,GG/57.29577951308232l;32.174049/
      DATA PSDN,PSD1,PHN,PSN,SN1,SN2,SPSN,CPSN,VT1/9*0.D0/
      DATA ANGMIN,ANGMAX/0.0000001,1.5707963/
C
      IF(ITH.NE.0) GO TO 50
C
C----INITIALIZE BANK ANGLE AND CONSTANTS FOR DETERMINISTIC
C     CONTROL MOTION CALCULATIONS
C
      CAA2=DEXP(-DT/TB)
      CA4=DT*DT/(12.D0*DEG)
      CA5=TB*(1.D0-CAA2)
      DT3=DT/2.D0
C
C----GENERATE Q ARRAY
      DO 1 I=1,9
      DO 1 J=1,9
      PE(I,J)=0.D0
      BDUM(I,J)=0.D0
      ADUM(I,J)=0.D0
      PP(I,J)=0.D0
      G(I,J)=0.D0
      R(I,J)=0.D0
      GAMMA(I,J)=0.D0
      W(I,J)=0.D0
    1 Q(I,J)=0.D0
      DT2=DT*DT/2.D0
      DT4=DT**3/6.D0
      W(1,1)=SIGW(1)**2
      W(2,2)=SIGW(2)**2
      W(3,3)=SIGW(3)**2
      GAMMA(1,1)=DT4
      GAMMA(2,1)=DT2
      GAMMA(3,1)=DT
      GAMMA(4,2)=DT4
      GAMMA(5,2)=DT2
      GAMMA(6,2)=DT
      GAMMA(7,3)=DT4
      GAMMA(8,3)=DT2
      GAMMA(9,3)=DT
      CALL TRANS(GAMMA,9,3,ADUM)
      CALL PROD(GAMMA,W,9,3,3,BDUM)
      CALL PROD(BDUM,ADUM,9,3,9,Q)
C
C----INITIALIZE COVARIANCE OF PREDICTION ARRAY (PP)
      DO 2 I=1,9
      DO 2 J=1,9
```

```
      PP(I,J)=0.D0                                                      LENT9130
    2 IF(I.EQ.J) PP(I,J)=1.D06                                          LENT9140
C                                                                       LENT9150
C----COMPUTE MEASUREMENT MATRIX AND VARIANCE                            LENT9160
      DO 3 I=1,9                                                        LENT9170
      DO 3 J=1,9                                                        LENT9180
    3 H(I,J)=0.D0                                                       LENT9190
      H(1,1)=1.D0                                                       LENT9200
      H(2,4)=1.D0                                                       LENT9210
      H(3,7)=1.D0                                                       LENT9220
      CALL TRANS(H,3,9,HT)                                              LENT9230
C                                                                       LENT9240
      SIG1(1)=SIG(1)                                                    LENT9250
      SIG1(2)=SIG(2)*1.D-03                                             LENT9260
      SIG1(3)=SIG(3)*1.D-03                                             LENT9270
      VARR=SIG1(1)**2                                                   LENT9280
      VARP=SIG1(2)**2                                                   LENT9290
      VART=SIG1(3)**2                                                   LENT9300
C                                                                       LENT9310
C----COMPUTE STATE TRANSITION ARRAY (PHI)                               LENT9320
      DO 4 I=1,9                                                        LENT9330
      DO 4 J=1,9                                                        LENT9340
      PHI(I,J)=0.D0                                                     LENT9350
    4 IF(I.EQ.J) PHI(I,J)=1.D0                                          LENT9360
      PHI(1,2)=DT                                                       LENT9370
      PHI(1,3)=DT2                                                      LENT9380
      PHI(2,3)=DT                                                       LENT9390
      PHI(4,5)=DT                                                       LENT9400
      PHI(4,6)=DT2                                                      LENT9410
      PHI(5,6)=DT                                                       LENT9420
      PHI(7,8)=DT                                                       LENT9430
      PHI(7,9)=DT2                                                      LENT9440
      PHI(8,9)=DT                                                       LENT9450
      CALL TRANS(PHI,9,9,PHITRN)                                        LENT9460
C                                                                       LENT9470
C----CREATE IDENTITY ARRAY                                              LENT9480
      DO 8 I=1,9                                                        LENT9490
      DO 8 J=1,9                                                        LENT9500
      XIDENT(I,J)=0.D0                                                  LENT9510
    8 IF(I.EQ.J) XIDENT(I,J)=1.D0                                       LENT9520
C                                                                       LENT9530
      PRINT 310,((H(I,J),J=1,9),I=1,9)                                  LENT9540
  310 FORMAT(///,10X,'H ARRAY',//,9(/,9F14.5))                          LENT9550
      PRINT 311,((GAMMA(I,J),J=1,9),I=1,9)                              LENT9560
  311 FORMAT(1H1,///,10X,'GAMMA ARRAY',//,9(/,9F14.5))                  LENT9570
      PRINT 312,((Q(I,J),J=1,9),I=1,9)                                  LENT9580
  312 FORMAT(///,10X,'Q ARRAY',//,9(/,9F14.5))                          LENT9590
      PRINT 313,((PP(I,J),J=1,9),I=1,9)                                 LENT9600
```

```
  313   FORMAT(///,10X,'PP ARRAY',//,9(/,9F14.5))                          LENT9610
        PRINT 316,((PHI(I,J),J=1,9),I=1,9)                                  LENT9620
  316   FORMAT(///,10X,'PHI ARRAY',//,9(/,9F14.4))                          LENT9630
C*********************************************************************     LENT9640
C                                                                          LENT9650
C----BEGIN NORMAL FILTER COMPUTATIONS                                      LENT9660
C                                                                          LENT9670
C----COMPUTE TRUE R,AZ,EL,ADD NOISE, AND COMPUTE NOISY MEASUREMENTS        LENT9680
C     IN CARTESIAN COORDINATES                                             LENT9690
   50   IF(NWLD.GE.0.AND.ITH.NE.0) GO TO 61                                 LENT9700
        RR=X2(1)*X2(1)+X2(2)*X2(2)                                          LENT9710
        A=DATAN2(X2(1),X2(2))                                               LENT9720
        E=DATAN2(X2(3),DSQRT(RR))                                           LENT9730
        RR=DSQRT(RR+X2(3)*X2(3))                                            LENT9740
        RM2=RR**2                                                           LENT9750
C                                                                          LENT9760
        CALL NORMAL(IU,RAN,3)                                               LENT9770
        DO 6 I=1,3                                                          LENT9780
    6   XDATA(I)=XDATA(I)+BIS(I)+SIG1(I)*RAN(I)                             LENT9790
C                                                                          LENT9800
        IF(DABS(A).LT.ANGMIN) A=ANGMIN                                      LENT9810
        IF(DABS(E).LT.ANGMIN) E=ANGMIN                                      LENT9820
        SIGNA=A/DABS(A)                                                     LENT9830
        SIGNE=E/DABS(E)                                                     LENT9840
        DELA=DABS(A-ANGMAX)                                                 LENT9850
        DELE=DABS(E-ANGMAX)                                                 LENT9860
        IF(DELA.LT.ANGMIN) A=SIGNA*ANGMAX                                   LENT9870
        IF(DELE.LT.ANGMIN) E=SIGNE*ANGMAX                                   LENT9880
C                                                                          LENT9890
        CA=DCOS(A)                                                          LENT9900
        SA=DSIN(A)                                                          LENT9910
        CE=DCOS(E)                                                          LENT9920
        SE=DSIN(E)                                                          LENT9930
        CA2=CA**2                                                           LENT9940
        SA2=SA**2                                                           LENT9950
        CE2=CE**2                                                           LENT9960
        SE2=SE**2                                                           LENT9970
        XDATA(3)=RR*SE                                                      LENT9980
        XDATA(2)=RR*CE*CA                                                   LENT9990
        XDATA(1)=RR*CE*SA                                                   LENT0010
C                                                                          LENT0020
        IF(ITH.NE.0) GO TO 63                                               LENT0030
        DO 62 I=1,3                                                         LENT0040
        X1P(I)=XDATA(I)                                                     LENT0050
        X1(I)=X1P(I)                                                        LENT0060
        XD1P(I)=SIG(I+3)                                                    LENT0070
        XDD1P(I)=0.D0                                                       LENT0080
   62   DELX(I)=0.D0                                                        LENT0090
```

```
      IF(NWLD.GE.0) GO TC 61                                            LENT0100
C                                                                       LENT0110
C----COMPUTE COVARIANCE OF MEASUREMENT ERROR ARRAY (R)                   LENT0120
   63 R(1,1)=RM2*(VART*SE2*SA2+VARP*CE2*CA2+VART*VARP*SE2*CA2)          LENT0130
     1     +VARR*CE2*SA2                                                LENT0140
      R(2,2)=RM2*(VART*SE2*CA2+VARP*CE2*CA2+VART*VARP*SE2*SA2)          LENT0150
     1     +VARR*CE2*CA2                                                LENT0160
      R(3,3)=RM2*VART*CE2+VARR*SE2                                      LENT0170
      R(1,2)=RM2*VART*(1.D0-VARP)*(SE2*SA*CA)                           LENT0180
     1      +(VARR-RM2*VARP)*(CE2*SA*CA)                                LENT0190
      R(2,1)=R(1,2)                                                     LENT0200
      R(1,3)=(VARR-RM2*VART)*SE*CE*SA                                   LENT0210
      R(3,1)=R(1,3)                                                     LENT0220
      R(2,3)=(VARR-RM2*VART)*SE*CE*CA                                   LENT0230
      R(3,2)=R(2,3)                                                     LENT0240
C                                                                       LENT0250
  121 IF(ITH.EQ.0)  PRINT 317,((R(I,J),J=1,9),I=1,9)                    LENT0260
  317 FORMAT(///,10X,'R ARRAY ',//,9(/,9F14.5),///)                     LENT0270
C                                                                       LENT0280
C----COMPUTE GAIN MATRIX                                                LENT0290
      DO 81 I=1,9                                                       LENT0300
      DO 81 J=1,9                                                       LENT0310
      BDUM(I,J)=0.D0                                                    LENT0320
   81 ADUM(I,J)=0.D0                                                    LENT0330
      CALL PROD(H,PP,3,9,9,ADUM)                                        LENT0340
      CALL PROD(ADUM,HT,3,9,3,BDUM)                                     LENT0350
      DO 83 I=1,9                                                       LENT0360
      DO 83 J=1,9                                                       LENT0370
   83 ADUM(I,J)=0.D0                                                    LENT0380
      CALL ADDSUB(BDUM,R,3,3,ADUM,1)                                    LENT0390
      DO 82 I=1,9                                                       LENT0400
      DO 82 J=1,9                                                       LENT0410
   82 BDUM(I,J)=0.D0                                                    LENT0420
      CALL INVERT(3,ADUM,BDUM,KER,9)                                    LENT0430
      IF(KER.EQ.2)  PRINT 308                                           LENT0440
  308 FORMAT(10X,25(1H*),'INVERSION SINGULARITY ENCOUNTERED')           LENT0450
      DO 84 I=1,9                                                       LENT0460
      DO 84 J=1,9                                                       LENT0470
   84 ADUM(I,J)=0.D0                                                    LENT0480
      CALL PROD(PP,HT,9,9,3,ADUM)                                       LENT0490
      CALL PROD(ADUM,BDUM,9,3,3,G)                                      LENT0500
      GNX=G(1,1)                                                        LENT0510
      GNY=G(4,2)                                                        LENT0520
      GNZ=G(7,3)                                                        LENT0530
C                                                                       LENT0540
C----COMPUTE COVARIANCE OF ESTIMATION ARRAY (PE)                        LENT0550
      DO 85 I=1,9                                                       LENT0560
      DO 85 J=1,9                                                       LENT0570
```

```
      ADUM(I,J)=0.D0
   85 BDUM(I,J)=0.D0
      CALL PRGD(G,H,9,3,9,ADUM)
      CALL ADDSUB(XIDENT,ADUM,9,9,BDUM,-1)
      CALL PRGD(BDUM,PP,9,9,9,PE)
C
C----COMPUTE COVARIANCE OF PREDICTION ARRAY (PP)
      DO 86 I=1,9
      DO 86 J=1,9
      ADUM(I,J)=0.D0
   86 BDUM(I,J)=0.D0
      CALL PRCD(PHI,PE,9,9,9,ADUM)
      CALL PRCD(ADUM,PHITRN,9,9,9,BDUM)
      CALL ADDSUB(BDUM,Q,9,9,PP,1)
   61 IF(ITH.LE.1) GO TO 66
C
C----COMPUTE NEW HEADING ANGLE AND HEADING ANGLE RATE, BASED ON
C    UNBIASED COMMANDS AS SENT FROM THE CONTROLLER.
C    PHN IS THE NEW ROLL ANGLE
C    PSDN IS THE NEW TURNING ANGLE RATE
C    PSN IS THE NEW HEADING ANGLE
      PHN=PHC+(PH1-PHC)*CAA2
      CA1=GG/VT1
      PSDN=CA1*PHN
      DELPS1= CA1*(PHC*DT+CA5*(PH1-PHC))
      PS1DEX=DELPS1/DT
      PSN=PS1+DELPS1
C
      CPSN=PSN/DEG
      SPSN=DSIN(CPSN)
      CPSN=DCOS(CPSN)
C
C----COMPUTE STATE PREDICTION VECTOR
   66 XD1P(1)=VT1*SPSN+DT*XDD1(1)
      XD1P(2)=VT1*CPSN+DT*XDD1(2)
      XD1P(3)=XD1(3)+DT*XDD1(3)
C
      DELX(1)=DT3*(XD1P(1)+SN1)-CA4*(XD1P(2)*PSDN-SN2*PSD1)
      DELX(2)=DT3*(XD1P(2)+SN2)-CA4*(-XD1P(1)*PSDN+SN1*PSD1)
      DELX(3)=XD1(3)*DT+XDD1(3)*DT2
C
      DO 110 I=1,3
      XDD1P(I)=XDD1(I)
      XD1P(I)=XD1P(I)+WR(I)
  110 X1P(I)=X1(I)+DT*WR(I)+DELX(I)
C
      IF(NWLD.LT.0) GO  TO 67
      DO 64 I=1,3
```

```
      X1(I)=X1P(I)
      XD1(I)=XD1P(I)
   64 XDD1(I)=XDD1P(I)
      GO TO 65
C
C----COMPUTE STATE ESTIMATION VECTOR
   67 E1=XDATA(1)-X1P(1)
      E2=XDATA(2)-X1P(2)
      E3=XDATA(3)-X1P(3)
C
      X1(1)=X1P(1)+G(1,1)*E1+G(1,2)*E2+G(1,3)*E3
      XD1(1)=XD1P(1)+G(2,1)*E1+G(2,2)*E2+G(2,3)*E3
      XDD1(1)=XDD1P(1)+G(3,1)*E1+G(3,2)*E2+G(3,3)*E3
      X1(2)=X1P(2)+G(4,1)*E1+G(4,2)*E2+G(4,3)*E3
      XD1(2)=XD1P(2)+G(5,1)*E1+G(5,2)*E2+G(5,3)*E3
      XDD1(2)=XDD1P(2)+G(6,1)*E1+G(6,2)*E2+G(6,3)*E3
      X1(3)=X1P(3)+G(7,1)*E1+G(7,2)*E2+G(7,3)*E3
      XD1(3)=XD1P(3)+G(8,1)*E1+G(8,2)*E2+G(8,3)*E3
      XDD1(3)=XDD1P(3)+G(9,1)*E1+G(9,2)*E2+G(9,3)*E3
C
      IF(ITH.GT.1) GO TO 65
      DO 98 I=1,3
   98 XDD1(I)=0.D0
C
C----COMPUTE VALUES FOR ENTERING DETERMINISTIC CONTROL
C    CALCULATIONS ON NEXT ITERATION
   65 IF(ITH.EQ.0) RETURN
      PH1=PHN
      PSD1=PSDN
      SN1=XD1(1)-WR(1)
      SN2=XD1(2)-WR(2)
      VT1=DSQRT(SN1*SN1+SN2*SN2)
      PS1=DATAN2(SN1,SN2)
      CPS=DCOS(PS1)
      SPS=DSIN(PS1)
      PS1=PS1*DEG
C
      RETURN
      END
C
C
C
C
C
C
C
C
      SUBROUTINE MATCAL
```

```
      REAL*8 A,AA,B,C,D,DD,S,X,Y
      DIMENSION AA(1),X(1),LL(9),MM(9),Y(9,9),S(1),D(1),
     1A(9,9),B(9,9),C(9,9)
C
C
      ENTRY INVERT(N,AA,X,KER,K)
C
C        THIS SUBROUTINE INVERTS THE MATRIX A AND LEAVES THE
C        RESULTS IN THE MATRIX X.   N AND K AREA THE ORDER OF THE MATRIX.
C        IF KER EQUALS 2 THEN A SINGULARITY HAS BEEN DETECTED.
C
      DO 1 I=1,N
      DO 1 J=1,N
      IND=(I-1)*K+J
    1 Y(I,J)=AA(IND)
C     KER=1
      N2=2*N
      CALL ARRAY(2,N,N,9,9,Y,Y)
      CALL DMINV(Y,N,DD,LL,MM)
      CALL ARRAY(1,N,N,9,9,Y,Y)
      IF(DD.EQ.0) KER=2
      DO 2 I=1,N
      DO 2 J=1,N
      IND=(I-1)*K+J
    2 X(IND)=Y(I,J)
      RETURN
C
C
      ENTRY ADDSUB(A,B,N,M,C,ISIGN)
C
C         THIS SUBROUTINE ADDS(ISIGN=1) OR SUBTRACTS(ISIGN=-1)
C         THE NXM MATRICES A AND B (A+B OR A-B) ,
C         STORING THE RESULT IN C.
C
      DO 125 I=1,N
      DO 125 J=1,M
  125 C(I,J)=A(I,J)+FLOAT(ISIGN)*B(I,J)
      RETURN
C
C
      ENTRY PROD(A,B,N,M,L,C)
C
C         THIS SUBROUTINE COMPUTES THE MATRIX PRODUCT AB
C         AND STORES THE RESULT IN C.  A IS NXM,B IS MXL, AND C IS NXL.
C
      DO 3 I=1,N
      DO 3 J=1,L
    3 C(I,J)=0.D0
```

```
      DO 126 I=1,N                                              LENT2020
      DO 126 J=1,L                                              LENT2030
      DO 126 K=1,M                                              LENT2040
  126 C(I,J)=C(I,J)+A(I,K)*B(K,J)                               LENT2050
      RETURN                                                    LENT2060
C                                                               LENT2070
C                                                               LENT2080
      ENTRY TRANS(A,N,M,C)                                      LENT2090
C                                                               LENT2100
C        THIS SUBROUTINE TRANSPOSES THE  NXM MATRIX A           LENT2110
C        AND STORES THE RESULT AS THE MXN MATRIX C.             LENT2120
C                                                               LENT2130
      DO 127 I=1,N                                              LENT2140
      DO 127 J=1,M                                              LENT2150
  127 C(J,I)=A(I,J)                                             LENT2160
      RETURN                                                    LENT2170
      END                                                       LENT2180
      SUBROUTINE ARRAY(MODE,I,J,N,M,S,D)                        LENT2190
      DIMENSION S(1),D(1)                                       LENT2200
      REAL*8 S,D                                                LENT2210
      NI=N-I                                                    LENT2220
      IF(MODE-1) 100,100,120                                    LENT2230
  100 IJ=I*J+1                                                  LENT2240
      NM=N*J+1                                                  LENT2250
      DO 110 K=1,J                                              LENT2260
      NM=NM-NI                                                  LENT2270
      DO 110 L=1,I                                              LENT2280
      IJ=IJ-1                                                   LENT2290
      NM=NM-1                                                   LENT2300
  110 D(NM)=S(IJ)                                               LENT2310
      GO TO 140                                                 LENT2320
  120 IJ=0                                                      LENT2330
      NM=0                                                      LENT2340
      DO 130 K=1,J                                              LENT2350
      DO 125 L=1,I                                              LENT2360
      IJ=IJ+1                                                   LENT2370
      NM=NM+1                                                   LENT2380
  125 S(IJ)=D(NM)                                               LENT2390
  130 NM=NM+NI                                                  LENT2400
  140 RETURN                                                    LENT2410
      END                                                       LENT2420
C                                                               LENT2430
C                                                               LENT2440
C                                                               LENT2450
C                                                               LENT2460
C                                                               LENT2470
C                                                               LENT2480
C                                                               LENT2490
```

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C                                                                         LENT2500
      SUBROUTINE DER                                                      LENT2510
      IMPLICIT REAL*8(A-H,O-Z)                                            LENT2520
      COMMON/DERCOM/EKDTAB(112),VKDTAB(112),D2W,HT,IPLC,NNT               LENT2530
      COMMON/DIFCOM/HMX,HMN,H,EROR,X,XMX,VDR(16,16),N,NAC,IFL,IFX,ISTF    LENT2540
      DATA G/32.174049/                                                   LENT2550
      VDR(12,1)=VDR(1,3)                                                  LENT2560
      VDR(12,2)=VDR(1,4)                                                  LENT2570
      GG=G*(1.D0-VDR(1,2)*(9.5897768D-08-VDR(1,2)*6.872006D-15))          LENT2580
      P=1.D0-6.875347D-06*VDR(1,2)*(1.D0-4.7948887D-08*VDR(1,2))          LENT2590
      PP=(-6.875347D-06*(1.D0-9.5897774D-08*VDR(1,2)))/P                  LENT2600
      PL=-D2W*.076475137*(P**4.2561222)                                   LENT2610
      P2=DSQRT(P)                                                         LENT2620
      VS=1116.4437*P2                                                     LENT2630
      V21=VDR(1,3)*VDR(1,3)                                               LENT2640
      V22=VDR(1,4)*VDR(1,4)                                               LENT2650
      V2=V21+V22                                                          LENT2660
      V=DSQRT(V2)                                                         LENT2670
      VM=V/VS                                                             LENT2680
      T  =EKDTAB(1)                                                       LENT2690
      TP  =0.D0                                                           LENT2700
      IF(VM.LE.VKDTAB(1))      GO TO 4                                    LENT2710
      T  =EKDTAB(NNT)                                                     LENT2720
      IF(VM.GE.VKDTAB(NNT))      GO TO 4                                  LENT2730
      IPLC=NNT/2                                                          LENT2740
    1 IF(VM.GT.VKDTAB(IPLC-1))      GO TO 2                               LENT2750
      IPLC=IPLC-1                                                         LENT2760
      GO TO 1                                                             LENT2770
    2 IF(VM.LE.VKDTAB(IPLC))      GO TO 3                                 LENT2780
      IPLC=IPLC+1                                                         LENT2790
      GO TO 2                                                             LENT2800
    3 D1=(VKDTAB(IPLC-1)-VKDTAB(IPLC  ))*(VKDTAB(IPLC-1)-VKDTAB(IPLC+1))LENT2810
      D2=(VKDTAB(IPLC  )-VKDTAB(IPLC-1))*(VKDTAB(IPLC  )-VKDTAB(IPLC+1))LENT2820
      D3=(VKDTAB(IPLC+1)-VKDTAB(IPLC-1))*(VKDTAB(IPLC+1)-VKDTAB(IPLC  ))LENT2830
      E1=(VM-VKDTAB(IPLC  ))*(VM-VKDTAB(IPLC+1))                          LENT2840
      E2=(VM-VKDTAB(IPLC-1))*(VM-VKDTAB(IPLC+1))                          LENT2850
      E3=(VM-VKDTAB(IPLC-1))*(VM-VKDTAB(IPLC  ))                          LENT2860
      T  =E1/D1*EKDTAB(IPLC-1)+E2/D2*EKDTAB(IPLC)+E3/D3*EKDTAB(IPLC+1)    LENT2870
      E1=VM+VM-VKDTAB(IPLC  )-VKDTAB(IPLC+1)                              LENT2880
      E2=VM+VM-VKDTAB(IPLC-1)-VKDTAB(IPLC+1)                              LENT2890
      E3=VM+VM-VKDTAB(IPLC-1)-VKDTAB(IPLC  )                              LENT2900
      TP  =E1/D1*EKDTAB(IPLC-1)+E2/D2*EKDTAB(IPLC)+E3/D3*EKDTAB(IPLC+1)   LENT2910
      TP=TP/VS                                                            LENT2920
    4 VDR(12,3)=PL*V*VDR(1,3)*T                                           LENT2930
      VDR(12,4)=PL*V*VDR(1,4)*T-GG                                        LENT2940
      VDR(12,5)=VDR(1,11)                                                 LENT2950
      VDR(12,6)=VDR(1,12)                                                 LENT2960
      VDR(12,7)=VDR(1,13)                                                 LENT2970
```

```
      VDR(12,8)=VDR(1,14)
      VDR(12,9)=VDR(1,15)
      VDR(12,10)=VDR(1,16)
      A44=4.2561222*T-.5D0*V*TP
      A32=PL*V*VDR(1,3)*PP*A44
      A33=PL*((V21+V2)/V*T+V21*TP)
      A34=PL*VDR(1,3)*VDR(1,4)*(T/V+TP)
      VDR(12,11)=A32*VDR(1, 8)+A33*VDR(1,11)+A34*VDR(1,14)
      VDR(12,12)=A32*VDR(1, 9)+A33*VDR(1,12)+A34*VDR(1,15)
      VDR(12,13)=A32*VDR(1,10)+A33*VDR(1,13)+A34*VDR(1,16)
      A42=PL*V*VDR(1,4)*PP*A44+G*(9.5897768D-08-VDR(1,2)*1.3944012D-14)
      A43=A34
      A44=PL*((V2+V22)/V*T+V22*TP)
      VDR(12,14)=A42*VDR(1, 8)+A43*VDR(1,11)+A44*VDR(1,14)
      VDR(12,15)=A42*VDR(1, 9)+A43*VDR(1,12)+A44*VDR(1,15)
      VDR(12,16)=A42*VDR(1,10)+A43*VDR(1,13)+A44*VDR(1,16)
      RETURN
      END
C
C
C
C
C
C
C
C
C
      SUBROUTINE OUT
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/DIFCOM/HMX,HMN,H,EROR,X,XMX,VDR(16,16),N,NAC,IFL,IFX,ISTF
      COMMON/DERCOM/EKDTAB(112),VKDTAB(112),D2W,HT,IPLC,NNT
      IF(X.EQ.0.D0)     JFL=1
      IF(JFL.GT.0)      GO TO 29
   27 G5=HT-VDR(1,2)
      G6=HT-VDR(2,2)
      G7=VDR(2,2)-VDR(1,2)
      G0=G5/G7
      G2=G0*G0
      G0=(G7-G6-G6)/G7*G2
      G2=G2*G6
      G3=G6/G7
      G3=G3*G3*G5
      XX=X-G0*H+G2/VDR(13,2)+G3/VDR(12,2)
      G5=XX-X
      G6=G5+H
      G0=G5/H
      G2=G0*G0
      G0=(H+G6+G6)/H*G2
```

```
      G2=G2*G6                                                          LENT3460
      G3=G6/H                                                           LENT3470
      G3=G3*G3*G5                                                       LENT3480
      G1=1.D0-G0                                                        LENT3490
      DO 2 I=1,10                                                       LENT3500
    2 VDR(1,I)=G0*VDR(2,I)+G1*VDR(1,I)+G2*VDR(13,I)+G3*VDR(12,I)        LENT3510
      X=XX                                                              LENT3520
      IFL=-1                                                            LENT3530
      VDR(4,1)=-VDR(1, 8)/VDR(1,4)                                      LENT3540
      VDR(4,2)=-VDR(1, 9)/VDR(1,4)                                      LENT3550
      VDR(4,3)=-VDR(1,10)/VDR(1,4)                                      LENT3560
      G3=VDR(1,3)                                                       LENT3570
      VDR(4,4)=VDR(1,5)+G3*VDR(4,1)                                     LENT3580
      VDR(4,5)=VDR(1,6)+G3*VDR(4,2)                                     LENT3590
      VDR(4,6)=VDR(1,7)+G3*VDR(4,3)                                     LENT3600
      GO TO 3                                                           LENT3610
   29 IF(VDR(1,2).LE.HT)      GO TO 27                                  LENT3620
      YP=VDR(1,2)+H*(VDR(12,2)-16.087D0*H)-HT                           LENT3630
      IF(YP.GT.0.D0)      GO TO 3                                       LENT3640
      YP=VDR(1,2)-HT                                                    LENT3650
      H=-(YP+YP)/(VDR(12,2)-DSQRT(VDR(12,2)*VDR(12,2)-2.D0*YP*VDR(12,4))LENT3660
     1)                                                                 LENT3670
      JFL=0                                                             LENT3680
    3 IF(X.GE.XMX)      IFL=-1                                          LENT3690
      RETURN                                                            LENT3700
      END                                                               LENT3710
C                                                                       LENT3720
C                                                                       LENT3730
C                                                                       LENT3740
C                                                                       LENT3750
C                                                                       LENT3760
C                                                                       LENT3770
C                                                                       LENT3780
C                                                                       LENT3790
      SUBROUTINE STIFF(SUBA,SUBB)                                       LENT3800
      IMPLICIT REAL*8 (A-H,O-Z)                                         LENT3810
      COMMON/DIFCOM/HMX,HMN,H,EROR,X,XMX,VDR(16,16),N,NAC,IFL,IFX,ISTF  LENT3820
      IF(NAC.LE.0)      NAC=N                                           LENT3830
      IFL=-2                                                            LENT3840
    1 CALL SUBA                                                         LENT3850
      CALL SUBB                                                         LENT3860
      IF(IFL+1)2,22,3                                                   LENT3870
    2 IST=0                                                             LENT3880
      F1P=EROR                                                          LENT3890
      EPL=.005D0*EROR                                                   LENT3900
      DO 200 I=1,N                                                      LENT3910
  200 VDR(11,I)=DABS(VDR(1,I))                                          LENT3920
      IFL=0                                                             LENT3930
```

```
    3 H2=H+H
      IF(FIP.GT.EPL.OR.IFX.GT.0.OR.DABS(H2).GT.HMX)      GO TO 4
      JST=IST/2
      KST=IST-JST-JST
      IF(KST.GT.0)       GO TO 4
      IST=JST
      H=H2
    4 IT=1
      XS=X
      H2=.5D0*H
      DO 5 I=1,N
      VDR(2,I)=VDR(1,I)
      VDR(10,I)=VDR(1,I)
      VDR(13,I)=VDR(12,I)
    5 VDR(16,I)=VDR(12,I)
    6 X=X+H2
      DO 7 I=1,N
    7 VDR(1,I)=VDR(10,I)+H2*VDR(16,I)
      CALL SUBA
      DO 8 I=1,N
      VDR(3,I)=VDR(1,I)
      VDR(14,I)=VDR(12,I)
    8 VDR(1,I)=VDR(10,I)+H2*VDR(12,I)
      CALL SUBA
      DO 10 I=1,N
      VDR(4,I)=VDR(1,I)
      VDR(15,I)=VDR(12,I)
      IF(ISTF.EQ.0)       GO TO 9
      P=VDR(4,I)-VDR(3,I)
      IF(P.EQ.0.D0)       GO TO 9
      P=-(VDR(15,I)-VDR(14,I))/P
      PH=P*H
      IF(PH.LT..5D0)       GO TO 9
      VDR(5,I)=P
      P=DEXP(-PH)
      VDR(6,I)=(1.D0-P)/PH
      VDR(7,I)=(1.D0-VDR(6,I))/PH
      VDR(8,I)=(.5D0-VDR(7,I))/PH
      VDR(1,I)=VDR(10,I)+H*((VDR(15,I)+VDR(15,I))*VDR(7,I)+VDR(13,I)*(VD
     1R(6,I)-VDR(7,I)-VDR(7,I))+VDR(14,I)*VDR(7,I)*PH)
      GO TO 10
    9 VDR(5,I)=0.D0
      VDR(1,I)=VDR(10,I)+H*VDR(15,I)
   10 CONTINUE
      X=X+H2
      CALL SUBA
      DO 12 I=1,N
      P=VDR(5,I)
```

```
      IF(ISTF.EQ.0.OR.P.EQ.0.D0)       GO TO 11                        LENT4420
      PH=VDR(6,I)*VDR(16,I)                                            LENT4430
      F1P=VDR(16,I)+P*VDR(10,I)                                        LENT4440
      F2P=VDR(14,I)+P*VDR( 3,I)                                        LENT4450
      F3P=VDR(15,I)+P*VDR( 4,I)                                        LENT4460
      F4P=VDR(12,I)+P*VDR( 1,I)                                        LENT4470
      VDR(1,I)=VDR(10,I)+H*(PH+VDR(7,I)*(-F1P-F1P-F1P+F2P+F2P+F3P+F3P-F4LENT4480
     1P)+4.D0*(F1P-F2P-F3P+F4P)*VDR(8,I))                             LENT4490
      GO TO 12                                                         LENT4500
   11 VDR(1,I)=VDR(10,I)+H/6.D0*(VDR(16,I)+VDR(14,I)+VDR(14,I)+VDR(15,I)LENT4510
     1+VDR(15,I)+VDR(12,I))                                            LENT4520
   12 CONTINUE                                                         LENT4530
      IF(IFX.GT.0)      GO TO 1                                        LENT4540
      IF(IT-2)13,15,17                                                 LENT4550
   13 DO 14 I=1,N                                                      LENT4560
   14 VDR(9,I)=VDR(1,I)                                                LENT4570
      X=XS                                                             LENT4580
      IT=2                                                             LENT4590
      H=H2                                                             LENT4600
      H2=.5D0*H                                                        LENT4610
      GO TO 6                                                          LENT4620
   15 CALL SUBA                                                        LENT4630
      DO 16 I=1,N                                                      LENT4640
      VDR(10,I)=VDR( 1,I)                                              LENT4650
   16 VDR(16,I)=VDR(12,I)                                              LENT4660
      IT=3                                                             LENT4670
      GO TO 6                                                          LENT4680
   17 F1P=0.D0                                                         LENT4690
      DO 18 I=1,N                                                      LENT4700
      F2P=(VDR(1,I)-VDR(9,I))/15.D0                                    LENT4710
      IF(I.GT.NAC)      GO TO 18                                       LENT4720
      F3P=DABS(F2P)                                                    LENT4730
      F4P=DABS(VDR(1,I))                                               LENT4740
      P=VDR(11,I)                                                      LENT4750
      IF(F4P.GT.P)      P=F4P                                          LENT4760
      IF(P.NE.0.D0)      F3P=F3P/P                                     LENT4770
      IF(F3P.GT.EROR)      GO TO 19                                    LENT4780
      IF(F3P.GT.F1P)      F1P=F3P                                      LENT4790
   18 VDR(1,I)=VDR(1,I)+F2P                                            LENT4800
      IST=IST+1                                                        LENT4810
      H=H+H                                                            LENT4820
      DO 180 I=1,N                                                     LENT4830
      F3P=DABS(VDR(1,I))                                               LENT4840
  180 IF(F3P.GT.VDR(11,I))      VDR(11,I)=F3P                          LENT4850
      GO TO 1                                                          LENT4860
   19 H=H2                                                             LENT4870
      IF(DABS(H2).GT.HMN)      GO TO 20                                LENT4880
      IFL=-1                                                           LENT4890
```

```
      GO TO 1
   20 X=XS
      H2=.5D0*H
      IT=2
      DO 21 I=1,N
      VDR( 9,I)=VDR(10,I)
      VDR(10,I)=VDR( 2,I)
   21 VDR(16,I)=VDR(13,I)
      IST=IST+IST
      GO TO 6
   22 RETURN
      END
C
C
C
C
C
C
C
C
      SUBROUTINE MATMAD(A,Z,X,Y)
      REAL*8  A(3,3),X(3),Y(3),Z(3)
      IGO=1
      GO TO 1
      ENTRY MATMLT(A,X,Y)
      IGO=0
    1 DO 2 I=1,3
      Y(I)=0.D0
      IF(IGO.NE.0)       Y(I)=Z(I)
      DO 2 J=1,3
    2 Y(I)=Y(I)+A(I,J)*X(J)
      RETURN
      END
C
C
C
C
C
C
C
C
      BLOCK DATA
C
C----SET ENTIRE COMMON BLOCK TO ZERO
      IMPLICIT REAL*8(Z)
      COMMON/AIRCOM/Z1(25)
      COMMON/RADCOM/Z2(37)
      COMMON/DERCOM/Z3(228)
```

```
      COMMON/DIFCOM/Z4(267)                                            LENT5380
      DATA Z1/25*0.D0/                                                 LENT5390
      DATA Z2/37*0.D0/                                                 LENT5400
      DATA Z3/228*0.D0/                                                LENT5410
      DATA Z4/267*0.D0/                                                LENT5420
      END                                                              LENT5430
C                                                                      LENT5440
C                                                                      LENT5450
C                                                                      LENT5460
C                                                                      LENT5470
C                                                                      LENT5480
C                                                                      LENT5490
C                                                                      LENT5500
C                                                                      LENT5510
//GO.SYSIN DD *
                                                                       LENT5520
                                                                       LENT5530
 15.0      0.1        0.1                                              LENT5540
                                                                       LENT5550
-50000.    20000.     10000.                                           LENT5560
 500.                                                                  LENT5570
 0.0        2.0       0.125      0.125      0.         0.              LENT5580
 10.       5.         6.         0.         1.         1.              LENT5590
 1.        1.         1.         1.         9999.                      LENT5600
 X RESIDUAL VS. T                                                      LENT5610
                                                                       LENT5620
 Y RESIDUAL VS. T                                                      LENT5630
                                                                       LENT5640
 Z RESIDUAL VS. T                                                      LENT5650
                                                                       LENT5660
 RADIAL RESIDUAL VS. T                                                 LENT5670
                                                                       LENT5680
 X6(1) VS. T                                                           LENT5690
                                                                       LENT5700
 X6(2) VS. T                                                           LENT5710
                                                                       LENT5720
 X6(2) VS. X6(1)                                                       LENT5730
                                                                       LENT5740
 LATERAL ERROR (XE) VS. T                                              LENT5750
                                                                       LENT5760
 LATERAL ERROR (EXPANDED SCALE) VS. T                                  LENT5770
                                                                       LENT5780
 LATERAL ERROR RATE (DXE) VS. T                                        LENT5790
                                                                       LENT5800
 PHD,PHD1, AND PHD2 VS. T                                              LENT5810
                                                                       LENT5820
 ROLL ANGLE(COMMAND,ACTUAL,&EST) VS. T                                 LENT5830
                                                                       LENT5840
```

```
BLANK-STITLE                                                              LENT5850
                                                                          LENT5860
X ACCELERATION ESTIMATE(XDD1(1)) VS. T                                    LENT5870
                                                                          LENT5880
Y ACCELERATION ESTIMATE(XDD1(2)) VS. T                                    LENT5890
                                                                          LENT5900
X ACCELERATION VS. Y ACCELERATION                                         LENT5910
                                                                          LENT5920
BLANK-WTITLE                                                              LENT5930
                                                                          LENT5940
BLANK-XTITLE                                                              LENT5950
                                                                          LENT5960
BLANK-YTITLE                                                              LENT5970
                                                                          LENT5980
BLANK-ZTITLE                                                              LENT5990
                                                                          LENT6000
 0.       0.        1.0        4.         23.6       144                  LENT6010
 7   7112 61 33 62 33 64 38  76 38144 85148 51                            LENT6020
0.     .0428 .81     .04285.82    .0429 .83    .04295.84    .0434 .85    .0441 LENT6030
.86    .0451 .87     .0464 .88    .0479 .89    .0499 .9     .0527 .905   .0543 LENT6040
.91    .056  .915    .0577 .92    .0595 .925   .0613 .93    .0631 .935   .065  LENT6050
.94    .0671 .945    .0691 .95    .0712 .955   .0734 .96    .0756 .965   .0779 LENT6060
.97    .0803 .975    .0827 .98    .0852 .985   .0878 .99    .0904 .995   .0931 LENT6070
1.     .0958 1.005   .0986 1.01   .1015 1.015  .1044 1.02   .1074 1.025  .1104 LENT6080
1.03   .1135 1.035   .1165 1.04   .1193 1.045  .1218 1.05   .1238 1.055  .1253 LENT6090
1.06   .1263 1.065   .127  1.07   .1276 1.075  .1283 1.08   .129  1.085  .1296 LENT6100
1.09   .1301 1.095   .1304 1.1    .1307 1.11   .1315 1.12   .132  1.13   .1323 LENT6110
1.14   .1325 1.15    .1326 1.16   .1328 1.17   .1331 1.18   .1334 1.19   .1336 LENT6120
1.2    .1339 1.21    .1342 1.22   .1344 1.23   .1347 1.24   .1349 1.25   .1352 LENT6130
1.26   .1355 1.27    .1357 1.28   .136  1.29   .1362 1.3    .1365 1.31   .1368 LENT6140
1.32   .137  1.33    .1373 1.34   .1376 1.35   .1378 1.36   .1381 1.37   .1384 LENT6150
1.38   .1386 1.39    .1389 1.4    .1391 1.41   .1393 1.42   .1394 1.43   .1395 LENT6160
1.44   .1395 1.45    .1394 1.46   .1393 1.47   .1392 1.48   .1391 1.49   .1389 LENT6170
1.5    .1387 1.51    .1384 1.52   .1381 1.53   .1379 1.54   .1376 1.55   .1373 LENT6180
1.56   .137  1.57    .1367 1.58   .1364 1.59   .1361 1.6    .1358 1.61   .1355 LENT6190
1.62   .1353 1.63    .135  1.64   .1347 1.65   .1345 1.66   .1343 1.67   .1342 LENT6200
1.68   .1341 1.69    .13395 1.7   .134  2.5    .13405                          LENT6210
0.     .0871 .44     .08715.46    .0878 .48    .0885 .5     .0891 .52    .0899 LENT6220
.54    .0907 .56     .0915 .58    .0925 .6     .0933 .62    .0943 .64    .0953 LENT6230
.66    .0962 .68     .0974 .7     .0985 .72    .0996 .74    .1007 .76    .1019 LENT6240
.9     .1106 .92     .1119 .94    .1133 .96    .1147 .98    .116  1.     .1174 LENT6250
1.02   .1188 1.04    .1202 1.06   .1215                                        LENT6260
.78    .103  .8      .1043 .82    .1054 .84    .1067 .86    .1089 .88    .1093 LENT6270
0.     .0549 .44     .05495.46    .0553 .48    .0556 .5     .0561 .52    .0565 LENT6280
.54    .0571 .56     .0576 .58    .0582 .6     .0588 .62    .0595 .64    .0601 LENT6290
.66    .0608 .68     .0615 .7     .062  .72    .0629 .74    .0637 .76    .0644 LENT6300
.78    .0651 .8      .0658 .82    .0665 .84    .0672 .86    .0679 .88    .0687 LENT6310
.9     .0697 .92     .0708 .94    .0723 .96    .074  .98    .0762 1.     .0785 LENT6320
```

```
1.02  .0811 1.04  .084  1.06  .0868                                     LENT6330
0.    .1646 .4    .1645 .6    .163  .7    .1618 .8    .1609 .9    .1618 LENT6340
.91   .1623 .92   .1629 .93   .164  .94   .1654 .95   .1674 .96   .1703 LENT6350
.97   .1744 .98   .1791 .99   .1863 1.    .1944 1.01  .2009 1.02  .2066 LENT6360
1.03  .211  1.04  .214  1.05  .2161 1.06  .2176 1.07  .2187 1.08  .2195 LENT6370
1.09  .2201 1.1   .2207 1.12  .2213 1.14  .2219 1.16  .2223 1.18  .2227 LENT6380
1.2   .223  1.3   .2223 1.4   .2188 1.5   .2144 1.6   .2097 1.7   .2066 LENT6390
1.8   .2046 2.5   .2042                                                 LENT6400
0.    .1619 .7    .1619 .75   .1619 .8    .1619 .85   .1619 .9    .162  LENT6410
.91   .162  .92   .1621 .93   .1621 .94   .1623 .95   .1624 .96   .1627 LENT6420
.97   .1634 .98   .165  .99   .1698 1.    .1837 1.01  .1953 1.02  .1989 LENT6430
1.03  .2002 1.04  .2011 1.05  .2017 1.06  .2022 1.07  .2023 1.08  .2026 LENT6440
1.1   .2029 1.12  .203  1.14  .2029 1.16  .2028 1.18  .2026 1.2   .202  LENT6450
1.3   .199  1.4   .1951 1.5   .1907 1.6   .1875 1.7   .1858 1.8   .1853 LENT6460
1.9   .1653 2.    .1853                                                 LENT6470
0.    .1048 .5    .1049 .52   .1052 .54   .1056 .56   .106  .58   .1065 LENT6480
.6    .1072 .62   .1079 .64   .1088 .66   .1098 .68   .111  .7    .1125 LENT6490
.72   .1142 .74   .1163 .76   .1186 .78   .1215 .8    .1243 .82   .1283 LENT6500
.84   .1329 .86   .1386 .88   .1453 .89   .1495 .9    .1543 .91   .1596 LENT6510
.92   .1658 .93   .1733 .94   .1818 .95   .1916 .96   .2024 .97   .2136 LENT6520
.98   .2258 .99   .2386 1.    .2523 1.01  .2655 1.02  .2777 1.03  .2878 LENT6530
1.04  .2965 1.05  .3043 1.06  .3104 1.07  .3157 1.08  .3204 1.09  .3248 LENT6540
1.1   .3286 1.11  .3323 1.12  .3353 1.13  .3379 1.14  .3414 1.15  .3442 LENT6550
1.16  .3467 1.17  .3495 1.18  .3521 1.19  .3545 1.2   .3567 1.21  .3589 LENT6560
1.22  .3607 1.23  .3627 1.24  .3644 1.26  .368  1.28  .3713 1.3   .3745 LENT6570
1.32  .3771 1.34  .3798 1.36  .3824 1.38  .3847 1.4   .3866 1.42  .3884 LENT6580
1.44  .39   1.46  .3912 1.48  .3923 1.5   .3931 1.52  .3939 1.54  .3945 LENT6590
1.56  .3951 1.58  .3954 1.6   .3958 1.65  .3966 1.7   .397  1.75  .3964 LENT6600
1.8   .3954 1.85  .3941 1.9   .3927 1.95  .3913 2.    .3901 2.1   .3896 LENT6610
3.    .38965                                                            LENT6620
0.    .0531 .8    .05315.82   .0532 .83   .0534 .84   .0541 .85   .0554 LENT6630
.86   .0571 .87   .0593 .88   .062  .89   .0651 .9    .0689 .91   .0732 LENT6640
.92   .0781 .93   .0845 .94   .0924 .95   .1018 .96   .1135 .97   .128  LENT6650
.98   .1431 .99   .1558 1.    .1665 1.01  .1757 1.02  .183  1.03  .1885 LENT6660
1.04  .1924 1.05  .1962 1.06  .1986 1.07  .2009 1.08  .2028 1.09  .2043 LENT6670
1.1   .2054 1.12  .2062 1.14  .2065 1.16  .2065 1.18  .2064 1.2   .2063 LENT6680
1.22  .2063 1.24  .2062 1.26  .2062 1.28  .2061 1.3   .206  1.4   .2055 LENT6690
1.5   .2043 1.6   .2026 1.7   .2009 1.8   .1993 1.9   .1976 2.    .196  LENT6700
2.2   .1926 2.5   .1876 3.    .1793                                     LENT6710
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```
C
C
C**********AN/TPQ-27 SIMULATION PROGRAM FOR COARSE GUIDANCE*************
C
C                    ROBERT E. LENTZ
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/AIRCOM/X3(3),XD3(3),WT(3),PHB,TB,DT,PHC,ITH
C
      COMMON/RADCOM/SIG(6),BIS(3),X1(3),XD1(3),PS1,PH1,WR(3),
     1                 DTRAD,SIGW(3),IU,NWLD
C
C----DIMENSION STORAGE FOR PLOTTING ARRAYS AND ARRAY TITLES
      REAL*4 XXA(200),XXB(200),XXC(200),XXD(200),XXE(200)
      REAL*4 YYA(200),YYB(200),YYC(200),YYD(200),YYE(200)
      REAL*8 ATITLE(12),BTITLE(12),CTITLE(12),DTITLE(12),ETITLE(12)
C
      DIMENSION XWP(5),YWP(5),THETA(5),H(4),VGH(4),PLENTH(4),
     1RANGE(4),AZ(4),TLEG(4),DEL(3),X2(3),DELNM(3),DX(3),DXD(3).WH(3),
     2VGX(4),VGY(4),X1NM(3),X2NM(3),X3NM(3),XWPNM(5),YWPNM(5)
C
      DATA RAD,G/57.295779513082321,32.174049/
      DATA PI,FEET,EPS/3.141592654,6076.1,0.0001/
      DATA G1,G2,PHILIM/4.0,4.0,30.0/
      DATA ITABA,ITAB1,IAVG.IEND.ITURN/4*0,-1/
      DATA T,TTURN1,TINTPN,TT21,TO21,SUMEST,SUMETR/7*0.D0/
      DATA HDE,XINT,YINT,TLEG1,XINTNM,YINTNM,TSTOP/6*0.D0,1.D06/
      DATA PHD1,PHD2,LNCLIM/2*0.0,72/
C
      NWLD=-1
      DEG=1./RAD
      TAN=DEG*PHILIM
      HEPMIN=5.0
C
C----DT IS CONTROL TIME INTERVAL
C    DTRAD IS RADAR SAMPLING INTERVAL
      IDTRAD=6
      DTRAD=FLOAT(IDTRAD)
      DT=1.0
      DTCON=DT
      IU=13521465
C
C----RADAR MEASUREMENT STANDARD DEVIATIONS AND RANDOM FORCING VALUES
      SIG(1)=900.
      SIG(2)=0.4
      SIG(3)=0.4
```

```
C                                                                       LENT0490
      SIGW(1)=0.0                                                       LENT0500
      SIGW(2)=0.0                                                       LENT0510
      SIGW(3)=0.0                                                       LENT0520
C                                                                       LENT0530
C----TB IS TRUE AIRCRAFT ROLL RESPONSE TIME CONSTANT                     LENT0540
C    TAUH IS THE ESTIMATED AIRCRAFT ROLL RESPONSE TIME CONSTANT          LENT0550
      TB=3.3                                                            LENT0560
      TAUH=TB                                                           LENT0570
C                                                                       LENT0580
C----READ INPUT PARAMETERS                                              LENT0590
      READ(5,100) NLEG,RANGEI,AZI,VA,VAH,VW,VWH,THETW,THETWH            LENT0600
      READ(5,110) (PLENTH(I),THETA(I),I=1,NLEG)                         LENT0610
      READ(5,111) HTG,DELNM                                             LENT0620
      READ(5,112) ATITLE                                                LENT0630
C                                                                       LENT0640
C----COMPUTE TRUE WIND (WT) AND ESTIMATED WIND (WH) COMPONENTS          LENT0650
      WT(1)=VW*DSIN(THETW*DEG)                                          LENT0660
      WT(2)=VW*DCOS(THETW*DEG)                                          LENT0670
      WT(3)=0.0                                                         LENT0680
      WH(1)=VWH*DSIN(THETWH*DEG)                                        LENT0690
      WH(2)=VWH*DCOS(THETWH*DEG)                                        LENT0700
      WH(3)=0.0                                                         LENT0710
      DO 2 I=1,3                                                        LENT0720
    2 WP(I)=WH(I)                                                       LENT0730
C                                                                       LENT0740
C----HTG IS INITIAL TRUE GROUND HEADING                                 LENT0750
C    HTA IS INITIAL TRUE AIR HEADING                                    LENT0760
C    VTG IS INITIAL TRUE GROUND SPEED                                   LENT0770
C    VA IS THE TRUE AIR SPEED THROUGHOUT PROBLEM                        LENT0780
      U1=VW*DSIN((THETW-HTG)*DEG)/VA                                    LENT0790
      HTA=HTG-RAD*DARSIN(U1)                                            LENT0800
      IF(HTA.LT.0.) HTA=HTA+360.                                        LENT0810
      IF(HTA.GT.360.) HTA=HTA-360.                                      LENT0820
      VTG=VW*DCOS((THETW-HTG)*DEG)+VA*DCOS((HTA-HTG)*DEG)               LENT0830
C                                                                       LENT0840
C----COMPUTE INITIAL TRUE A/C VELOCITY                                  LENT0850
      XD3(1)=VTG*DSIN(HTG*DEG)                                          LENT0860
      XD3(2)=VTG*DCOS(HTG*DEG)                                          LENT0870
      XD3(3)=0.                                                         LENT0880
C                                                                       LENT0890
C----COMPUTE LEG PARAMETERS FOR MISSION DATA TABLE                      LENT0900
C    XWP,YWP ARE COORDINATES OF LEG START/STOP POINTS                   LENT0910
C    RANGE IS AVG DISTANCE TO LEG FROM RADAR; AZ IS AVG ANGLE TO LEG    LENT0920
C    H IS DESIRED AIR SPEED HEADING ALONG LEG                           LENT0930
C    VGH IS DESIRED GROUND SPEED ALONG LEG                              LENT0940
C    VGX,VGY ARE COMPONENTS OF VGH                                      LENT0950
      XWP(1)=RANGEI*FEET*DSIN(AZI*DEG)                                  LENT0960
```

```
      YWP(1)=RANGEI*FEET*DCOS(AZI*DEG)                                  LENT0970
      XWPNM(1)=XWP(1)/FEET                                              LENT0980
      YWPNM(1)=YWP(1)/FEET                                              LENT0990
      XMAX=XWPNM(1)                                                     LENT1000
      XMIN=XWPNM(1)                                                     LENT1010
      YMAX=YWPNM(1)                                                     LENT1020
      YMIN=YWPNM(1)                                                     LENT1030
C                                                                       LENT1040
C----COMPUTE INITIAL TRUE A/C POSITION                                  LENT1050
      DO 9 KK=1,3                                                       LENT1060
    9 DEL(KK)=DELNM(KK)*FEET                                            LENT1070
      X3(1)=XWP(1)+DEL(1)                                               LENT1080
      X3(2)=YWP(1)+DEL(2)                                               LENT1090
      X3(3)=DEL(3)                                                      LENT1100
      DO 10 KK=1,3                                                      LENT1110
   10 X3NM(KK)=X3(KK)/FEET                                              LENT1120
C                                                                       LENT1130
C----PRINT OUT SIMULATION INITIAL CONDITIONS AND PARAMETERS             LENT1140
      PRINT 1000,VW,THETW,WT(1),WT(2),VWH,THETWH,WH(1),WH(2),           LENT1150
     1           SIG(1),SIG(2),SIG(3),BIS,SIG(4),SIG(5),SIG(6),         LENT1160
     2           SIGW,DTRAD,DELNM,VTG,HTG,XD3(1),XD3(2),VA,HTA,TB       LENT1170
      PRINT 1001,NLEG,RANGEI,AZI,XWPNM(1),YWPNM(1),DTCON,PHILIM,        LENT1180
     1           G1,G2,HERMIN                                           LENT1190
C                                                                       LENT1200
C                                                                       LENT1210
C----COMPUTE MISSION DATA TABLE                                         LENT1220
      DO 120    I=1,NLEG                                                LENT1230
      XWP(I+1)=XWP(I)+PLENTH(I)*FEET*DSIN(DEG*THETA(I))                 LENT1240
      YWP(I+1)=YWP(I)+PLENTH(I)*FEET*DCOS(DEG*THETA(I))                 LENT1250
      XWPNM(I+1)=XWP(I+1)/FEET                                          LENT1260
      YWPNM(I+1)=YWP(I+1)/FEET                                          LENT1270
      RANGE(I)=0.5*DSQRT((XWP(I)+XWP(I+1))**2+(YWP(I)+YWP(I+1))**2)/FEETLENT1280
      AZ(I)=RAD*DATAN2(XWP(I)+XWP(I+1),YWP(I)+YWP(I+1))                 LENT1290
      U1=VWH*DSIN((THETWH-THETA(I))*DEG)/VAH                            LENT1300
      H(I)=THETA(I)-RAD*DARSIN(U1)                                      LENT1310
      IF(H(I).LT.0.) H(I)=H(I)+360.                                     LENT1320
      IF(H(I).GE.360.) H(I)=H(I)-360.                                   LENT1330
      VGH(I)=VAH*DCOS(DEG*(H(I)-THETA(I)))                              LENT1340
     1       +VWH*DCOS(DEG*(THETWH-THETA(I)))                           LENT1350
      TLEG(I)=(PLENTH(I)*FEET)/VGH(I)                                   LENT1360
      VGX(I)=VGH(I)*DSIN(THETA(I)*DEG)                                  LENT1370
  120 VGY(I)=VGH(I)*DCOS(THETA(I)*DEG)                                  LENT1380
C                                                                       LENT1390
C----SET UP X2 VECTOR WHICH WILL PLOT AS DESIRED TRACK                  LENT1400
      DO 123 I=1.NLEG                                                   LENT1410
      ITABA=ITABA+1                                                     LENT1420
      X2NM(1)=XWPNM(I)                                                  LENT1430
      X2NM(2)=YWPNM(I)                                                  LENT1440
```

```
      XXC(ITABA)=X2NM(1)
      YYC(ITABA)=X2NM(2)
      DT2PLT=TLEG(I)/DTRAD
      IDT2=DT2PLT
      DO 121 J=1,IDT2
      ITABA=ITABA+1
      X2NM(1)=X2NM(1)+(DTRAD*VGX(I))/FEET
      X2NM(2)=X2NM(2)+(DTRAD*VGY(I))/FEET
      IF(X2NM(1).GT.XMAX)  XMAX=X2NM(1)
      IF(X2NM(1).LT.XMIN)  XMIN=X2NM(1)
      IF(X2NM(2).LT.YMIN)  YMIN=X2NM(2)
      IF(X2NM(2).GT.YMAX)  YMAX=X2NM(2)
      XXC(ITABA)=X2NM(1)
  121 YYC(ITABA)=X2NM(2)
  123 CONTINUE
C
C----SET UP PROBLEM INITIAL CONDITIONS
      I=1
      CALCST=2.0*DTRAD+1.0-EPS
      CALCS1=CALCST+1.0
      HSTART=H(1)
      HNEXT=H(2)
C
      PRINT 1100,I,XWPNM(I),YWPNM(I),XWPNM(I+1),YWPNM(I+1),PLENTH(I),
     1          THETA(I),VGH(I),H(I),RANGE(I),AZ(I),TLEG(I)
      PRINT 1101
      PRINT 1200
      LNC=3
C
C**********************************************************************
C
C----BEGIN MAIN PROCESSING STREAM
C
C----THE ARCRFT SUBROUTINE CALCULATES TRUE NEW POSITION AND
C    VELOCITY OF THE AIRCRAFT IN CARTESIAN COORDINATES
  191 CALL ARCRFT
      DO 192 KK=1,3
  192 X3NM(KK)=X3(KK)/FEET
C
C----THE RADAR SUBROUTINE CALCULATES THE ESTIMATED POSITION
C    AND VELOCITY OF THE AIRCRAFT IN CARTESIAN COORDINATES
      CALL RADAR6
      DO 203  KK=1,3
  203 X1NM(KK)=X1(KK)/FEET
C
C----CALCULATE HEADINGS AND ERRORS FOR USE IN CONTROL CALCULATION
C    HTG IS TRUE GROUNG HEADING
C    HEG IS THE ESTIMATED GROUNG HEADING
```

```
C     HTA IS TRUE AIR SPEED HEADING
C     HEA IS THE ESTIMATED AIR SPEED HEADING
       HTG=DATAN2(XD3(1),XD3(2))*RAD
       HTA=DATAN2((XD3(1)-WT(1)),(XD3(2)-WT(2)))*RAD
       IF(T.LT.(DTRAD-EPS)) GO TO 205
       HEA=DATAN2((XD1(1)-WH(1)),(XD1(2)-WH(2)))*RAD
       HEG=DATAN2(XD1(1),XD1(2))*RAD
       VEG=DSQRT(XD1(1)**2+XD1(2)**2)
       GO TO 206
 205   HEA=0.D0
       HEG=0.D0
C
 206   IF(HTG.GT.360.) HTG=HTG-360.
       IF(HEG.GT.360.) HEG=HEG-360.
       IF(HTA.GT.360.) HTA=HTA-360.
       IF(HEA.GT.360.) HEA=HEA-360.
       IF(HTG.LT.   0.) HTG=HTG+360.
       IF(HEG.LT.   0.) HEG=HEG+360.
       IF(HTA.LT.   0.) HTA=HTA+360.
       IF(HEA.LT.   0.) HEA=HEA+360.
C
C----ETRUE IS THE TRUE A/C DISPLACEMENT FROM DESIRED TRACK
C     EEST IS THE ESTIMATED DISPLACEMENT OF A/C FROM THE
C     DESIRED TRACK
       ETRUE=(X3(1)-XWP(I))*DCOS(THETA(I)*DEG)/FEET
     1       -(X3(2)-YWP(I))*DSIN(THETA(I)*DEG)/FEET
       EEST=(X1(1)-XWP(I))*DCOS(THETA(I)*DEG)/FEET
     1       -(X1(2)-YWP(I))*DSIN(THETA(I)*DEG)/FEET
       IF(ITURN.NE.0) GO TO 2058
       IF(IEND.EQ.1) GO TO 2058
       ETRUE1=(X3(1)-XWP(I+1))*DCOS(THETA(I+1)*DEG)/FEET
     1       -(X3(2)-YWP(I+1))*DSIN(THETA(I+1)*DEG)/FEET
       EEST1=(X1(1)-XWP(I+1))*DCOS(THETA(I+1)*DEG)/FEET
     1       -(X1(2)-YWP(I+1))*DSIN(THETA(I+1)*DEG)/FEET
       IF(DABS(ETRUE1).LT.DABS(ETRUE)) ETRUE=ETRUE1
       IF(DABS(EEST1).LT.DABS(EEST)) EEST=EEST1
C
C----COMPUTE OFF TRACK ERROR RMS SUMS
2053   IAVG=IAVG+1
       SUMEST=SUMEST+EEST**2
       SUMETR=SUMETR+ETRUE**2
C
C----COMPUTE PLOTTING LIMITS FOR SCALING
       IF(MOD(ITH,IDTRAD).NE.0) GO TO 2059
       ITAB1=ITAB1+1
       IF(X1NM(1).GT.XMAX) XMAX=X1NM(1)
       IF(X3NM(1).GT.XMAX) XMAX=X3NM(1)
       IF(X1NM(1).LT.XMIN) XMIN=X1NM(1)
```

```
      IF(X3NM(1).LT.XMIN) XMIN=X3NM(1)                                  LENT2410
      IF(X1NM(2).LT.YMIN) YMIN=X1NM(2)                                  LENT2420
      IF(X3NM(2).LT.YMIN) YMIN=X3NM(2)                                  LENT2430
      IF(X1NM(2).GT.YMAX) YMAX=X1NM(2)                                  LENT2440
      IF(X3NM(2).GT.YMAX) YMAX=X3NM(2)                                  LENT2450
      XXA(ITAB1)=X1NM(1)                                                LENT2460
      YYA(ITAB1)=X1NM(2)                                                LENT2470
      XXB(ITAB1)=X3NM(1)                                                LENT2480
      YYB(ITAB1)=X3NM(2)                                                LENT2490
C                                                                       LENT2500
2059  IF(T.LT.CALCST) GO TO 207                                         LENT2510
      IF(ITURN.EQ.0.OR.IEND.EQ.1) GO TO 207                             LENT2520
C                                                                       LENT2530
C----COMPUTE TURN ANGLE AND TIME                                        LENT2540
      XMI=XD1(2)/XD1(1)                                                 LENT2550
      XMI1=(YWP(I+1)-YWP(I+2))/(XWP(I+1)-XWP(I+2))                      LENT2560
      XINT=-(YWP(I+1)-X1(2)+XMI*X1(1)-XMI1*XWP(I+1))/(XMI1-XMI)         LENT2570
      YINT=XMI*XINT-XMI*X1(1)+X1(2)                                     LENT2580
      XINTNM=XINT/FEET                                                  LENT2590
      YINTNM=YINT/FEET                                                  LENT2600
      DTG=DSQRT((XINT-X1(1))**2+(YINT-X1(2))**2)                        LENT2610
      TLEG1=DTG/VEG                                                     LENT2620
      DELH=DABS(H(I+1)-HEA)                                             LENT2630
      IF(DELH.GT.180.) DELH=360.-DELH                                   LENT2640
      TO21=VAH*DELH*DEG/(2.0*G*TAN)                                     LENT2650
      IF(TO21/TAUH.GT.0.6) GO TO 2060                                   LENT2660
      TT21=TAUH*DSQRT(2.0*TO21/TAUH)                                    LENT2670
      GO TO 2061                                                        LENT2680
C                                                                       LENT2690
C----COMPUTE TURN HALF PERIOD BY SOLVING EQUATION                       LENT2700
C    USING THE NEWTON-RAPHSON METHOD                                    LENT2710
2060  TT21=TAUH*(1.0+TO21/TAUH)                                         LENT2720
2061  U=TT21/TAUH                                                       LENT2730
      DO 2062 J=1,10                                                    LENT2740
      F=U+DEXP(-U)-1.0-TO21/TAUH                                        LENT2750
      FP=1.0-DEXP(-U)                                                   LENT2760
      UOLD=U                                                            LENT2770
      U=UOLD-F/FP                                                       LENT2780
      IF(DABS(TAUH*(U-UOLD)).LE.0.01) GO TO 2063                        LENT2790
2062  CONTINUE                                                          LENT2800
2063  TT21=TAUH*U                                                       LENT2810
C                                                                       LENT2820
      DA1=VEG*(TT21-TO21)                                               LENT2830
      DC1=2.*VWH*TO21*DSIN(DEG*(THETA(I+1)-THETWH))                     LENT2840
     1   *DSIN(DEG*(THETA(I+1)-HEG))                                    LENT2850
      DB1=VAH*VAH/G/TAN*(DSIN(DEG*(H(I+1)-HEA))*DSIN(DEG*(THETA(I+1)-   LENT2860
     2HEA))-(1.-DCOS(DEG*(H(I+1)-HEA)))*DCOS(DEG*(THETA(I+1)-HEA)))     LENT2870
     3/DABS(DSIN(DEG*(THETA(I+1)-HEA)))                                 LENT2880
```

```
      D61=DA1+DB1+DC1
C
      TTURN1=D61/VEG
      TSTPTN=2.0*(TT21-TAUH)
      TTOTTN=2.0*TT21
      TG=TLEG1-TTURN1
C
  207 IF(LNC.LE.LNCLIM) GO TO 208
      PRINT 1101
      PRINT 1200
      LNC=3
  208 LNC=LNC+2
      PRINT 1201,T,PHC,PH1,TLEG1,TTURN1,TO21,TT21,
     1           HTG,HEG,HTA,HEA,
     2           ETRUE,EEST,PHD1,PHD2
C
C----T IS TIME
C    TG IS TIME TO GO BEFORE BEGINNING COMMAND TURN
C    ITH COUNTS TOTAL NUMBER OF SAMPLES ON THIS RUN
      ITH=ITH+1
      T=T+DT
      IF(T.LT.CALCS1) GO TO 191
      IF(T.GE.TSTOP) GO TO 999
C
C----BRANCH TO 210 IF NOT EXECUTING OR COMPLETING A TURN
C    BRANCH TO 220 WHEN TIME TO BEGIN A TURN
C    BRANCH TO 209 WHEN COMPLETING A TURN
      IF(ITURN) 210,220,209
  209 IF(TG.LE.0.0.AND.IEND.NE.1) GO TO 219
      GO TO 240
  210 IF(TG.LE.0.0.AND.IEND.NE.1) GO TO 219
C
C----GENERATE COURSE GUIDANCE TO CAUSE AIRCRAFT TO FLY
C    TOWARD CURRENT LEG'S END POINT.  BANK ANGLE COMMAND IS
C    QUANTIZED TO NEAREST 15/128 DEGREE.  PHC=0 COMMAND SENT IF
C    HEADING ERROR TO CURRENT LEG END POINT IS LESS THAN HERMIN.
      IF(TG.GT.3.0*TAUH+DT.OR.IEND.EQ.1) GO TO 212
      PHC=0.0
      GO TO 191
C
  212 HEGWPT=RAD*DATAN2((XWP(I+1)-X1(1)),(YWP(I+1)-X1(2)))
      HDEOLD=HDE
      HDE=HEGWPT-HEG
      IF(HDE.GT.180.) HDE=HDE-360.
      IF(HDE.LT.-180.) HDE=HDE+360.
      HDEDOT=(HDE-HDEOLD)/DT
      PHD1=G1*HDE
      PHD2=G2*HDEDOT
```

```
      PHD=PHD1+PHD2
      IF(DABS(PHD).GT.PHILIM) PHD=PHILIM*PHD/DABS(PHD)
C
      PHC=(PHD)*128.D0/15.D0+.5D0
      NHC=PHC
      PHC=NHC
      PHC=PHC*15.D0/128.D0
C
C
      IF(DABS(HDE).LT.HERMIN) PHC=0.0
      GO TO 191
C
 219  ITURN=0
C
C----NWLD IS SET GREATER THAN ZERO HERE TO SUPPRESS RADAR UPDATES
C     DURING A COMMAND TURN
      NWLD=1
      TINTRN=0.0
      IF(LNC.LE.LNCLIM) GO TO 2191
      PRINT 1101
      LNC=0
2191  LNC=LNC+3
      PRINT 2001, T, TINTRN
 220  IF(TINTRN.GE.TSTPTN) GO TO 239
      TINTRN=TINTRN+DT
      TTOTT1=TTOTTN
C
C----COMPUTE DIRECTION OF COMMAND TURN
      DELH=HNEXT-HSTART
      IF(DELH.GT.180.) DELH=DELH-360.
      IF(DELH.LT.-180.) DELH=DELH+360.
      IF(DELH.GT.0.) PHC=PHILIM
      IF(DELH.LT.0.) PHC=-PHILIM
      GO TO 191
C
 239  ITURN=1
      IF(LNC.LE.LNCLIM) GO TO 2391
      PRINT 1101
      LNC=0
2391  LNC=LNC+3
      PRINT 2002, T,TINTRN
      PHC=0.
C
C----BEGIN NEW LEG
      I=I+1
      HSTART=H(I)
      HNEXT=H(I+1)
      IF(I.EQ.NLEG) IEND=1
```

```
C
      IF(LNC.LE.LNCLIM-21) GO TO 2392
      PRINT 1101
      LNC=0
 2392 LNC=LNC+21
C
      PRINT 1100,I,XWPNM(I),YWPNM(I),XWPNM(I+1),YWPNM(I+1),PLENTH(I),
     1          THETA(I),VGH(I),H(I),RANGE(I),AZ(I),TLEG(I)
      PRINT 1200
C
  240 IF(TINTRN.GE.TTOTT1) GO TO 280
      TINTRN=TINTRN+DT
      GO TO 191
C
C----RESET TURN LOGIC FOR TURN AT END OF NEW LEG
  280 ITURN=-1
      NALD=-1
      IF(LNC.LE.LNCLIM) GO TO 285
      PRINT 1101
      LNC=0
  285 LNC=LNC+3
      PRINT 2003, T,TINTRN
      TINTRN=0.
      IF(IEND.EQ.1) TSTOP=T+TLEG(I)-2.0*TT21-2.0*TAUH
      GO TO 191
C
  999 CONTINUE
      RMSEST=DSQRT(SUMEST/FLOAT(IAVG))
      RMSETR=DSQRT(SUMETR/FLOAT(IAVG))
      PRINT 1260, RMSETR,RMSEST
C
C----EXECUTE PLOTS
      ITAB2=ITAB1+1
      ITAB3=ITAB1+2
      DXX=XMAX-XMIN
      DYY=YMAX-YMIN
      IF(DXX.GT.DYY) YMAX=YMIN+DXX
      IF(DXX.LT.DYY) XMAX=XMIN+DYY
      XXA(ITAB2)=XMAX
      XXA(ITAB3)=XMIN
      YYA(ITAB2)=YMAX
      YYA(ITAB3)=YMIN
      WRITE(6,1250) ATITLE
      CALL PLOTP(XXA,YYA,ITAB3,1)
      CALL PLOTP(XXB,YYB,ITAB1,2)
      CALL PLOTP(XXC,YYC,ITABA,3)
      PRINT 1101
      STOP
```

```
C
C----INPUT FORMATS
 100  FORMAT(I1,F9.2,7F10.4)
 110  FORMAT(2F10.3)
 111  FORMAT(4F10.3)
 112  FORMAT(6A8)
C
C----OUTPUT FORMATS
C
1000  FORMAT(1H1,48X,'AN/TPQ-27 SIMULATION',//,37X,'COARSE ',
     1'GUIDANCE MODE WITH KALMAN FILTERING',///,5X,'INITIAL CONDITIONS :
     2',//,8X,'TRUE WIND = ',F6.2,' FT/SEC AT ',F6.2,' DEGREES',
     3/,8X,'TRUE WIND COMPONENTS = ',2F6.2,/,
     48X,'ESTIMATED WIND = ',F6.2,' FT/SEC AT ',F6.2,' DEGREES',/,
     58X,'ESTIMATED WIND COMPONENTS = ',2F6.2,//,
     6/,8X,'RADAR DATA',//,10X,
     6'MEASUREMENT SIGMAS(R(FT.),AZ(DEG),EL(DEG)) = ',1P3D16.5,/,10X
     7,'MEASUREMENT BIASES(          "             ) = ' ,1P3D16.5,/,
     810X,'INITIAL VELOCITY MEASUREMENT VALUES = ',7X,1P3D16.5,/,
     910X,'RANDOM FORCING ASSUMPTION VALUES (SIGW) = ',3X,1P3D16.5,/,
     C10X,'SAMPLING INTERVAL FOR RADAR (DTRAD) = ',0PF6.3,///,
     18X,'AIRCRAFT DATA',//,
     210X,'TRUE INITIAL DISPLACEMENT FROM STARTING POINT (NM) = ',
     32F8.2,/,10X,'TRUE INITIAL GROUND VELOCITY = ',F8.2,
     4' FT/SEC AT ',F6.2,' DEGREES',/,
     510X,'TRUE INITIAL GROUND VELOCITY COMPONENTS = ',2F8.2,/,
     610X,'TRUE INITAL AIR VELOCITY = ',F8.2,' FT/SEC AT ',
     7F6.2,' DEGREES',/,10X,'ROLL RESPONSE PARAMETER (TB) = ',F5.3,///)
C
1001  FORMAT(8X,'TRACK DATA',//,10X,'NUMBER OF LEGS (NLEGS) = ',I2,/,
     110X,'POSITION OF FIRST LEG = ',F8.3,' NM AT ',F6.2,' DEGREES',/,
     210X,'COMPONENTS OF START POINT = ',2F8.3,//,15X,
     3///,8X,'CONTROL DATA',//,10X,'CONTROL INTERVAL = ',F6.3,/,
     410X,'MAXIMUM BANK ANGLE = ',F7.2,//,
     510X,'G1 = ',F8.3,/,10X,'G2 = ',F8.3,//,
     610X,'MIN HEADING ERROR ANGLE FOR COMMAND CORRECTION = ',
     7F8.3,///)
C
1100  FORMAT(//,4X,'LEG NUMBER',I2,//,10X,'LEG START POINT (X,Y) = ',
     12F10.4,/,10X,'LEG END POINT (X,Y) = ',2X,2F10.4,//,
     210X,'LEG LENGTH (NM) = ',2X,F10.2,/,10X,'LEG AZIMUTH (DEG) = ',
     3F10.2,//,10X,'DESIRED GROUND SPEED (FT/SEC) = ',F7.2,/,
     410X,'DESIRED AIR HEADING (DEG) = ',F6.2,//,
     510X,'AVG RANGE OF LEG FROM RADAR (NM) = ',3X,F10.2,/,
     610X,'AVG AZIMUTH OF LEG FROM RADAR (DEG) = ',F10.2,//,
     710X,'TLEG = ',F7.3,///)
C
1101  FORMAT(1H1)
```

```
C
1200  FORMAT(4X,'T',7X,'PHC',7X,'PH1',5X,'TLEG1',4X,'TTURN1',6X,'TO21'
     C,6X,'TT21',
     14X,'HTG',4X,'HEG',4X,'HTA',4X,'HFA',4X,'ETRUE',5X,'EEST',5X,
     22X,'PHD1',5X,'PHD2',//)
C
1201  FORMAT(1X,F6.2,6F10.4,4F7.2,4F9.4,/)
C
1250  FORMAT(1H1,10X,6A8,//,11X,6A8,///)
C
1260  FORMAT(///,10X,'RMS ETRUE = ',F10.6,//,11X,'RMS EEST = ',F10.6)
C
2001  FORMAT(10X,'STARTING TURN  T = ',F6.2,8X,'TINTRN = ',F6.2,//)
2002  FORMAT(10X,'TURN ENDING    T = ',F6.2,8X,'TINTRN = ',F6.2,//)
2003  FORMAT(10X,'TURN COMPLETE  T = ',F6.2,8X,'TINTRN = ',F6.2,//)
      END
C
C
C
C
C
C
C
C
      SUBROUTINE ARCRFT
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/AIRCOM/X3(3),XD3(3),WT(3),PHB,TB,DT,PHC,ITH
C
      DATA DEG,G/57.295779513082321,32.174049/
C
C----FIRST TIME THROUGH, ITH=0
      IF(ITH)4,1,4
C
C----SUBTRACT TRUE WIND VELOCITY
    1 SM1=XD3(1)-WT(1)
      SM2=XD3(2)-WT(2)
C
C----VT IS AIRSPEED OF A/C
C    PHB IS AUTOPILOT BANK ANGLE BIAS
C    TB IS A/C RESPONSE LOOP TIME CONSTANT
C    PS IS INITIAL TURN ANGLE
C    PSD IS INITIAL TURN RATE
      VT=DSQRT(SM1*SM1+SM2*SM2)
      PHB=0.D0
      PH=PHB
      CA1=G/VT
```

```
      CA2=DEXP(-DT/TB)
      CA3=CA1
      CA4=DT*DT/(12.D0*DEG)
      CA5=TB*(1.D0-CA2)
      DT3=.5D0*DT
      PSD=CA1*PH
      PS=DATAN2(SM1,SM2)
      CPS=DCOS(PS)
      SPS=DSIN(PS)
      PS=PS*DEG
      RETURN
C
C*********************************************************************
C
C----ENTER MAIN CALCULATION STREAM
C
C----PHC IS NOW THE COMMAND BANK ANGLE AT T(N-1)
C     PHN IS THE NEW BANK ANGLE
C     PSDN IS THE NEW TURNING RATE
C     PSN IS NEW HEADING ANGLE FOR VELOCITY WITH RESPECT TO WIND
    4 PSN=PHB+PHC
      PHN=PSN+(PH-PSN)*CA2
      PSDN=CA1*PHN
      PSN=PS+CA3*(PSN*DT+CA5*(PH-PSN))
      CPSN=PSN/DEG
      SPSN=DSIN(CPSN)
      CPSN=DCOS(CPSN)
C
C----UPDATE VELOCITY VECTOR FOR NEW TURN ANGLE
      XD3(1)=WT(1)+VT*SPSN
      XD3(2)=WT(2)+VT*CPSN
      XD3(3)=0.D0
C
C----UPDATE POSITION VECTOR FOR NEW TURN ANGLE
      SM1=DT3*(SPS+SPSN)-CA4*(CPSN*PSDN-CPS*PSD)
      SM2=DT3*(CPS+CPSN)-CA4*(-SPSN*PSDN+SPS*PSD)
      SM3=0.D0
C
      X3(1)=DT*WT(1)+VT*SM1+X3(1)
      X3(2)=DT*WT(2)+VT*SM2+X3(2)
      X3(3)=X3(3)
C----RESET VALUES FOR NEXT TIME IN SUBROUTINE
      PH=PHN
C
      PS=PSN
      PSD=PSDN
      SPS=SPSN
      CPS=CPSN
```

```
      RETURN                                                            LENT5770
      END                                                               LENT5780
C                                                                       LENT5790
C                                                                       LENT5800
C                                                                       LENT5810
C                                                                       LENT5820
C                                                                       LENT5830
C                                                                       LENT5840
C                                                                       LENT5850
C                                                                       LENT5860
      SUBROUTINE RADAR6                                                 LENT5870
      IMPLICIT REAL*8 (A-H,O-Z)                                         LENT5880
      REAL*4 RAN(3)                                                     LENT5890
C                                                                       LENT5900
      COMMON/AIRCOM/X3(3),XD3(3),WT(3),PHB,TB,DT,PHC,ITH                LENT5910
C                                                                       LENT5920
      COMMON/RADCOM/SIG(6),BIS(3),X1(3),XD1(3),PS1,PH1,WR(3),           LENT5930
     1              DTRAD,SIGW(3),IU,NWLD                               LENT5940
C                                                                       LENT5950
      DIMENSION Q(6,6),GAMMA(6,6),ADUM(6,6),BDUM(6,6),W(6,6),           LENT5960
     1PP(6,6),PE(6,6),H(6,6),HT(6,6),R(6,6),PHI(6,6),SIG1(3),           LENT5970
     2PHITRN(6,6),G(6,6),XIDENT(6,6),X1P(3),XD1P(3),XDATA(3),DELX(3)    LENT5980
C                                                                       LENT5990
      EQUIVALENCE (XDATA(1),RR),(XDATA(2),A),(XDATA(3),E)               LENT6000
C                                                                       LENT6010
      DATA DEG,GG/57.295779513082321,32.174049/                         LENT6020
      DATA PSDN,PSD1,PHN,PSN,SN1,SN2,SPSN,CPSN,VT1/9*0.D0/              LENT6030
      DATA ANGMIN,ANGMAX,EPS/0.0000001,1.5707963,0.0001/                LENT6040
C                                                                       LENT6050
      IF(ITH.NE.0) GO TO 50                                             LENT6060
C                                                                       LENT6070
      INT=DTRAD/DT+0.5                                                  LENT6080
      DTCUM=DTRAD                                                       LENT6090
C                                                                       LENT6100
C-----COMPUTE BANK ANGLE CONSTANTS FOR DETERMINISTIC CONTROL MOTION     LENT6110
      CAA2=DEXP(-DT/TB)                                                 LENT6120
      CA4=DT**2/(12.D0*DEG)                                             LENT6130
      CA5=TB*(1.D0-CAA2)                                                LENT6140
      DT3=DT/2.D0                                                       LENT6150
C                                                                       LENT6160
C-----GENERATE Q ARRAY                                                  LENT6170
      DO 1 I=1,6                                                        LENT6180
      DO 1 J=1,6                                                        LENT6190
      PE(I,J)=0.D0                                                      LENT6200
      BDUM(I,J)=0.D0                                                    LENT6210
      ADUM(I,J)=0.D0                                                    LENT6220
      PP(I,J)=0.D0                                                      LENT6230
      G(I,J)=0.D0                                                       LENT6240
```

```
      R(I,J)=0.D0                                                       LENT6250
      GAMMA(I,J)=0.D0                                                   LENT6260
      W(I,J)=0.D0                                                       LENT6270
    1 Q(I,J)=0.D0                                                       LENT6280
      DTRAD2=DTRAD**2/2.D0                                              LENT6290
      W(1,1)=SIGW(1)**2                                                 LENT6300
      W(2,2)=SIGW(2)**2                                                 LENT6310
      W(3,3)=SIGW(3)**2                                                 LENT6320
      GAMMA(1,1)=DTRAD2                                                 LENT6330
      GAMMA(2,1)=DTRAD                                                  LENT6340
      GAMMA(3,2)=DTRAD2                                                 LENT6350
      GAMMA(4,2)=DTRAD                                                  LENT6360
      GAMMA(5,3)=DTRAD2                                                 LENT6370
      GAMMA(6,3)=DTRAD                                                  LENT6380
      CALL TRANS(GAMMA,6,3,ADUM)                                        LENT6390
      CALL PROD(GAMMA,W,6,3,3,BDUM)                                     LENT6400
      CALL PROD(BDUM,ADUM,6,3,6,Q)                                      LENT6410
C                                                                       LENT6420
C----INITIALIZE COVARIANCE OF PREDICTION ARRAY (PP)                     LENT6430
      DO 2 I=1,6                                                        LENT6440
      DO 2 J=1,6                                                        LENT6450
      PP(I,J)=0.D0                                                      LENT6460
    2 IF(I.EQ.J) PP(I,J)=1.D06                                          LENT6470
C                                                                       LENT6480
C----COMPUTE MEASUREMENT MATRIX AND VARIANCE                            LENT6490
      DO 3 I=1,6                                                        LENT6500
      DO 3 J=1,6                                                        LENT6510
    3 H(I,J)=0.D0                                                       LENT6520
      H(1,1)=1.D0                                                       LENT6530
      H(2,3)=1.D0                                                       LENT6540
      H(3,5)=1.D0                                                       LENT6550
      CALL TRANS(H,3,6,HT)                                              LENT6560
C                                                                       LENT6570
      SIG1(1)=SIG(1)                                                    LENT6580
      SIG1(2)=SIG(2)/DEG                                                LENT6590
      SIG1(3)=SIG(3)/DEG                                                LENT6600
      VARR=SIG1(1)**2                                                   LENT6610
      VARP=SIG1(2)**2                                                   LENT6620
      VART=SIG1(3)**2                                                   LENT6630
C                                                                       LENT6640
C----COMPUTE STATE TRANSITION ARRAY (PHI)                               LENT6650
      DO 4 I=1,6                                                        LENT6660
      DO 4 J=1,6                                                        LENT6670
    4 PHI(I,J)=0.D0                                                     LENT6680
      PHI(1,1)=1.D0                                                     LENT6690
      PHI(1,2)=DTRAD                                                    LENT6700
      PHI(2,2)=1.D0                                                     LENT6710
      PHI(3,3)=1.D0                                                     LENT6720
```

```
      PHI(3,4)=DTRAD                                                    LENT6730
      PHI(4,4)=1.DO                                                     LENT6740
      PHI(5,5)=1.DO                                                     LENT6750
      PHI(5,6)=DTRAD                                                    LENT6760
      PHI(6,6)=1.DO                                                     LENT6770
      CALL TRANS(PHI,6,6,PHITRN)                                        LENT6780
C                                                                       LENT6790
C----CREATE IDENTITY ARRAY                                              LENT6800
      DO 8 I=1,6                                                        LENT6810
      DO 8 J=1,6                                                        LENT6820
      XIDENT(I,J)=0.DO                                                  LENT6830
    8 IF(I.EQ.J) XIDENT(I,J)=1.DO                                       LENT6840
C                                                                       LENT6850
C----BYPASS PRINT EQUATIONS FOR THIS PROGRAM                            LENT6860
      IF(ITH.GT.-10) GO TO 50                                           LENT6870
      PRINT 310,((H(I,J),J=1,6),I=1,6)                                  LENT6880
  310 FORMAT(1H1,///,10X,'H ARRAY',//,6(/,6F17.5))                      LENT6890
      PRINT 311,((GAMMA(I,J),J=1,6),I=1,6)                              LENT6900
  311 FORMAT(///,10X,'GAMMA ARRAY',//,6(/,6F17.5))                      LENT6910
      PRINT 312,((Q(I,J),J=1,6),I=1,6)                                  LENT6920
  312 FORMAT(///,10X,'Q ARRAY',//,6(/,6F17.5))                          LENT6930
      PRINT 313,((PP(I,J),J=1,6),I=1,6)                                 LENT6940
  313 FORMAT(///,10X,'PP ARRAY',//,6(/,6F17.5))                         LENT6950
      PRINT 314,((PE(I,J),J=1,6),I=1,6)                                 LENT6960
  314 FORMAT(///,10X,'PE ARRAY',//,6(/,6F17.5))                         LENT6970
      PRINT 316,((PHI(I,J),J=1,6),I=1,6)                                LENT6980
  316 FORMAT(///,10X,'PHI ARRAY',//,6(/,6F17.4))                        LENT6990
C*********************************************************************** LENT7000
C                                                                       LENT7010
C----BEGIN NORMAL FILTER COMPUTATIONS                                   LENT7020
C                                                                       LENT7030
C----COMPUTE TRUE R,AZ,EL,ADD NOISE, AND COMPUTE NOISY MEASUREMENTS     LENT7040
C     IN CARTESIAN COORDINATES                                          LENT7050
   50 DTCUM=DTCUM+DT                                                    LENT7060
      IF(DTCUM.LT.(DTRAD-EPS)) GO TO 61                                 LENT7070
      IF(NWLD.GE.0.AND.ITH.NE.0) GO TO 61                               LENT7080
      RR=X3(1)*X3(1)+X3(2)*X3(2)                                        LENT7090
      A=DATAN2(X3(1),X3(2))                                             LENT7100
      E=DATAN2(X3(3),DSQRT(RR))                                         LENT7110
      RR=DSQRT(RR+X3(3)*X3(3))                                          LENT7120
      RM2=RR**2                                                         LENT7130
C                                                                       LENT7140
      CALL NORMAL(IU,RAN,3)                                             LENT7150
      DO 6 I=1,3                                                        LENT7160
    6 XDATA(I)=XDATA(I)+BIS(I)+SIG1(I)*RAN(I)                           LENT7170
C                                                                       LENT7180
      IF(DABS(A).LT.ANGMIN) A=ANGMIN                                    LENT7190
      IF(DABS(E).LT.ANGMIN) E=ANGMIN                                    LENT7200
```

```
      SIGNA=A/DABS(A)                                                   LENT7210
      SIGNE=E/DABS(E)                                                   LENT7220
      DELA=DABS(A-ANGMAX)                                               LENT7230
      DELE=DABS(E-ANGMAX)                                               LENT7240
      IF(DELA.LT.ANGMIN) A=SIGNA*ANGMAX                                 LENT7250
      IF(DELE.LT.ANGMIN) E=SIGNE*ANGMAX                                 LENT7260
C                                                                       LENT7270
      CA=DCOS(A)                                                        LENT7280
      SA=DSIN(A)                                                        LENT7290
      CE=DCOS(E)                                                        LENT7300
      SE=DSIN(E)                                                        LENT7310
      CA2=CA**2                                                         LENT7320
      SA2=SA**2                                                         LENT7330
      CE2=CE**2                                                         LENT7340
      SE2=SE**2                                                         LENT7350
C                                                                       LENT7360
      XDATA(3)=RR*SE                                                    LENT7370
      XDATA(2)=RR*CE*CA                                                 LENT7380
      XDATA(1)=RR*CE*SA                                                 LENT7390
C                                                                       LENT7400
      IF(ITH.NE.0) GO TO 63                                             LENT7410
      DO 62 I=1,3                                                       LENT7420
      X1P(I)=XDATA(I)                                                   LENT7430
      X1(I)=X1P(I)                                                      LENT7440
      XD1P(I)=SIG(I+3)                                                  LENT7450
   62 DELX(I)=0.D0                                                      LENT7460
      IF(NWLD.GE.0) GO TO 61                                            LENT7470
C                                                                       LENT7480
C----COMPUTE COVARIANCE OF MEASUREMENT ERROR ARRAY (R)                  LENT7490
   63 R(1,1)=RM2*(VART*SE2*SA2+VARP*CE2*CA2+VAPT*VARP*SE2*CA2)          LENT7500
     1       +VARR*CE2*SA2                                              LENT7510
      R(2,2)=RM2*(VART*SE2*CA2+VARP*CE2*CA2+VART*VARP*SE2*SA2)          LENT7520
     1       +VARR*CE2*CA2                                              LENT7530
      R(3,3)=RM2*VART*CE2+VARR*SE2                                      LENT7540
      R(1,2)=RM2*VART*(1.D0-VARP)*(SE2*SA*CA)                           LENT7550
     1        +(VARR-RM2*VARP)*(CE2*SA*CA)                              LENT7560
      R(2,1)=R(1,2)                                                     LENT7570
      R(1,3)=(VARR-RM2*VART)*SE*CE*SA                                   LENT7580
      R(3,1)=R(1,3)                                                     LENT7590
      R(2,3)=(VARR-RM2*VART)*SE*CE*CA                                   LENT7600
      R(3,2)=R(2,3)                                                     LENT7610
C                                                                       LENT7620
  121 IF(ITH.EQ.-10)  PRINT 317,((R(I,J),J=1,6),I=1,6)                  LENT7630
  317 FORMAT(///,10X,'R ARRAY ',//,6(/,6F17.5),///)                     LENT7640
C                                                                       LENT7650
C----COMPUTE GAIN MATRIX (G)                                            LENT7660
      DO 81 I=1,6                                                       LENT7670
      DO 81 J=1,6                                                       LENT7680
```

```
      BDUM(I,J)=0.DO                                              LENT7690
   81 ADUM(I,J)=0.DO                                              LENT7700
      CALL PROD(H.PP,3,6,6,ADUM)                                  LENT7710
      CALL PROD(ADUM,HT,3,6,3,BDUM)                               LENT7720
      DO 83 I=1,6                                                 LENT7730
      DO 83 J=1,6                                                 LENT7740
   83 ADUM(I,J)=0.DO                                              LENT7750
      CALL ADDSUB(BDUM,R,3,3,ADUM,1)                              LENT7760
      DO 82 I=1,6                                                 LENT7770
      DO 82 J=1,6                                                 LENT7780
   82 BDUM(I,J)=0.DO                                              LENT7790
      CALL INVERT(3,ADUM,BDUM,KER,6)                              LENT7800
      IF(KER.EQ.2)  PRINT 308                                     LENT7810
  308 FORMAT(10X,25(1H*),'INVERSION SINGULARITY ENCOUNTERED')     LENT7820
      DO 84 I=1,6                                                 LENT7830
      DO 84 J=1,6                                                 LENT7840
   84 ADUM(I,J)=0.DO                                              LENT7850
      CALL PROD(PP,HT,6,6,3,ADUM)                                 LENT7860
      CALL PROD(ADUM.BDUM,6,3,3,G)                                LENT7870
      GNX=G(1,1)                                                  LENT7880
      GNY=G(3,2)                                                  LENT7890
      GNZ=G(5,3)                                                  LENT7900
C                                                                 LENT7910
C----COMPUTE COVARIANCE OF ESTIMATION ARRAY (PE)                  LENT7920
      DO 85 I=1,6                                                 LENT7930
      DO 85 J=1,6                                                 LENT7940
      ADUM(I,J)=0.DO                                              LENT7950
   85 BDUM(I,J)=0.DO                                              LENT7960
      CALL PROD(G.H,6,3,6,ADUM)                                   LENT7970
      CALL ADDSUB(XIDENT,ADUM,6,6,BDUM,-1)                        LENT7980
      CALL PROD(BDUM,PP,6,6,6,PE)                                 LENT7990
C                                                                 LENT8000
C----COMPUTE COVARIANCE OF PREDICTION ARRAY (PP)                  LENT8010
      DO 86 I=1,6                                                 LENT8020
      DO 86 J=1,6                                                 LENT8030
      ADUM(I,J)=0.DO                                              LENT8040
   86 BDUM(I,J)=0.DO                                              LENT8050
      CALL PROD(PHI,PE,6,6,6,ADUM)                                LENT8060
      CALL PROD(ADUM,PHITRN,6,6,6,BDUM)                           LENT8070
      CALL ADDSUB(BDUM,Q,6,6,PP,1)                                LENT8080
C                                                                 LENT8090
C----BYPASS DETERMINISTIC FORCING EQUATIONS FOR FIRST             LENT8100
C    SAMPLING PERIOD OF DTRAD                                     LENT8110
   61 IF(ITH.LE.INT) GO TO 66                                     LENT8120
C                                                                 LENT8130
C----COMPUTE NEW HEADING ANGLE AND HEADING ANGLE RATE, BASED ON   LENT8140
C    UNBIASED COMMANDS AS SENT FROM THE CONTROLLER.               LENT8150
C    PHN IS THE NEW ROLL ANGLE                                    LENT8160
```

```
C     PSDN IS THE NEW TURNING ANGLE RATE
C     PSN IS THE NEW HEADING ANGLE
      PHN=PHC+(PHI-PHC)*CAA2
      CA1=GG/VT1
      PSDN=CA1*PHN
      DELPS1= CA1*(PHC*DT+CA5*(PHI-PHC))
      PS1DEX=DELPS1/DT
      PSN=PS1+DELPS1
C
      CPSN=PSN/DEG
      SPSN=DSIN(CPSN)
      CPSN=DCOS(CPSN)
C
C----COMPUTE STATE PREDICTION VECTOR
   66 XD1P(1)=VT1*SPSN
      XD1P(2)=VT1*CPSN
      XD1P(3)=XD1(3)
C
      DELX(1)=DT3*(XD1P(1)+SN1)-CA4*(XD1P(2)*PSDN-SN2*PSD1)
      DELX(2)=DT3*(XD1P(2)+SN2)-CA4*(-XD1P(1)*PSDN+SN1*PSD1)
      DELX(3)=DT*XD1(3)
C
      DO 110 I=1,3
      XD1P(I)=XD1P(I)+WR(I)
  110 X1P(I)=X1(I)+DT*WR(I)+DELX(I)
C
      IF(DTCUM.LT.DTRAD-EPS) GO TO 97
      DTCUM=0.D0
      IF(NWLD.LT.0) GO  TO 67
C
   97 DO 64 I=1,3
      X1(I)=X1P(I)
   64 XD1(I)=XD1P(I)
      GO TO 65
C
C----COMPUTE STATE ESTIMATION VECTOR
   67 E1=XDATA(1)-X1P(1)
      E2=XDATA(2)-X1P(2)
      E3=XDATA(3)-X1P(3)
C
      X1(1)=X1P(1)+G(1,1)*E1+G(1,2)*E2+G(1,3)*E3
      XD1(1)=XD1P(1)+G(2,1)*E1+G(2,2)*E2+G(2,3)*E3
      X1(2)=X1P(2)+G(3,1)*E1+G(3,2)*E2+G(3,3)*E3
      XD1(2)=XD1P(2)+G(4,1)*E1+G(4,2)*E2+G(4,3)*E3
      X1(3)=X1P(3)+G(5,1)*E1+G(5,2)*E2+G(5,3)*E3
      XD1(3)=XD1P(3)+G(6,1)*E1+G(6,2)*E2+G(6,3)*E3
C
C----COMPUTE VALUES FOR ENTERING DETERMINISTIC CONTROL
```

```
C     CALCULATIONS ON NEXT ITERATION                                    LENT8650
   65 IF(ITH.LT.INT) RETURN                                             LENT8660
      PH1=PHN                                                           LENT8670
      PSD1=PSDN                                                         LENT8680
      SN1=XD1(1)-WR(1)                                                  LENT8690
      SN2=XD1(2)-WR(2)                                                  LENT8700
      VT1=DSQRT(SN1*SN1+SN2*SN2)                                        LENT8710
      PS1=DATAN2(SN1,SN2)                                               LENT8720
      CPS=DCOS(PS1)                                                     LENT8730
      SPS=DSIN(PS1)                                                     LENT8740
      PS1=PS1*DEG                                                       LENT8750
      RETURN                                                            LENT8760
      END                                                               LENT8770
C                                                                       LENT8780
C                                                                       LENT8790
C                                                                       LENT8800
C                                                                       LENT8810
C                                                                       LENT8820
C                                                                       LENT8830
C                                                                       LENT8840
C                                                                       LENT8850
      SUBROUTINE MATCAL                                                 LENT8860
      REAL*8 A,AA,B,C,D,DD,S,X,Y                                        LENT8870
      DIMENSION AA(1),X(1),LL(6),MM(6),Y(6,6),S(1),D(1),                LENT8880
     1A(6,6),B(6,6),C(6,6)                                              LENT8890
C                                                                       LENT8900
C                                                                       LENT8910
      ENTRY INVERT(N,AA,X,KER,K)                                        LENT8920
C                                                                       LENT8930
C       THIS SUBROUTINE INVERTS THE MATRIX A AND LEAVES THE             LENT8940
C       RESULTS IN THE MATRIX X.    N AND K AREA THE ORDER OF THE MATRIX.LENT8950
C       IF KER EQUALS 2 THEN A SINGULARITY HAS BEEN DETECTED.           LENT8960
C                                                                       LENT8970
      DO 1 I=1,N                                                        LENT8980
      DO 1 J=1,N                                                        LENT8990
      IND=(I-1)*K+J                                                     LENT9000
    1 Y(I,J)=AA(IND)                                                    LENT9010
C     KER=1                                                             LENT9020
      N2=2*N                                                            LENT9030
      CALL ARRAY(2,N,N,6,6,Y,Y)                                         LENT9040
      CALL DMINV(Y,N,DD,LL,MM)                                          LENT9050
      CALL ARRAY(1,N,N,6,6,Y,Y)                                         LENT9060
      IF(DD.EQ.0) KER=2                                                 LENT9070
      DO 2 I=1,N                                                        LENT9080
      DO 2 J=1,N                                                        LENT9090
      IND=(I-1)*K+J                                                     LENT9100
    2 X(IND)=Y(I,J)                                                     LENT9110
      RETURN                                                            LENT9120
```

```
C
C
      ENTRY ADDSUB(A,B,N,M,C,ISIGN)
C
C        THIS SUBROUTINE ADDS(ISIGN=1) OR SUBTRACTS(ISIGN=-1)
C        THE NXM MATRICES A AND B (A+B OR A-B) ,
C        STORING THE RESULT IN C.
C
      DO 125 I=1,N
      DO 125 J=1,M
  125 C(I,J)=A(I,J)+FLOAT(ISIGN)*B(I,J)
      RETURN
C
C
      ENTRY PROD(A,B,N,M,L,C)
C
C        THIS SUBROUTINE COMPUTES THE MATRIX PRODUCT AB
C        AND STORES THE RESULT IN C.  A IS NXM,B IS MXL, AND C IS NXL.
C
      DO 3 I=1,N
      DO 3 J=1,L
    3 C(I,J)=0.D0
      DO 126 I=1,N
      DO 126 J=1,L
      DO 126 K=1,M
  126 C(I,J)=C(I,J)+A(I,K)*B(K,J)
      RETURN
C
C
      ENTRY TRANS(A,N,M,C)
C
C        THIS SUBROUTINE TRANSPOSES THE  NXM MATRIX A
C        AND STORES THE RESULT AS THE MXN MATRIX C.
C
      DO 127 I=1,N
      DO 127 J=1,M
  127 C(J,I)=A(I,J)
      RETURN
      END
      SUBROUTINE ARRAY(MODE,I,J,N,M,S,D)
      DIMENSION S(1),D(1)
      REAL*8 S,D
      NI=N-I
      IF(MODE-1) 100,100,120
  100 IJ=I*J+1
      NM=N*J+1
      DO 110 K=1,J
      NM=NM-NI
```

```
      DO 110 L=1,I                                                      LENT9610
      IJ=IJ-1                                                           LENT9620
      NM=NM-1                                                           LENT9630
110   D(NM)=S(IJ)                                                       LENT9640
      GO TO 140                                                         LENT9650
 120  IJ=0                                                              LENT9660
      NM=0                                                              LENT9670
      DO 130 K=1,J                                                      LENT9680
      DO 125 L=1,I                                                      LENT9690
      IJ=IJ+1                                                           LENT9700
      NM=NM+1                                                           LENT9710
 125  S(IJ)=D(NM)                                                       LENT9720
 130  NM=NM+MI                                                          LENT9730
 140  RETURN                                                            LENT9740
      END                                                               LENT9750
C                                                                       LENT9760
C                                                                       LENT9770
C                                                                       LENT9780
C                                                                       LENT9790
C                                                                       LENT9800
C                                                                       LENT9810
C                                                                       LENT9820
C                                                                       LENT9830
      BLOCK DATA                                                        LENT9840
      IMPLICIT REAL*8(Z)                                                LENT9850
      COMMON/AIRCOM/Z1(14)                                              LENT9860
      COMMON/RADCOM/Z2(26)                                              LENT9870
      DATA Z1/14*0.0/                                                   LENT9880
      DATA Z2/26*0.0/                                                   LENT9890
      END                                                               LENT9900
C                                                                       LENT9910
C                                                                       LENT9920
C                                                                       LENT9930
C                                                                       LENT9940
C                                                                       LENT9950
C                                                                       LENT9960
C                                                                       LENT9970
C                                                                       LENT9980
//GO.SYSIN DD *
3   50.       45.        500.      500.      50.0      50.0       45.0     45.0
 10.0         0.0
 10.0          90.
14.1414       225.
  15.0        2.0        2.0
 DESIRED,TRUE, AND ESTIMATED POSITION
```

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